THE DESIGN OF A MECHANICAL REFERENCING SYSTEM FOR THE REAR DRUM OF THE LONGWALL SHEARER COAL MINER

Contract No.
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FINAL REPORT

E. William Jones
and
Thomas Chen-Hsing Yang

Awarded by

Marshall Space Flight Center of NASA
Huntsville, Al.

To

Mississippi State University
Mississippi State, MS. 39762

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ABSTRACT

The design of two systems which reference the position of a Longwall Shearer Coal Miner to the mine roof of the present cut and of the last cut are presented. This system is part of an automation system that will guide the rear cutting drum in such a manner that the total depth of cut remains constant even though the front drum may be following an undulating roof profile.

The rear drum referencing mechanism continually monitors the distance from the mine roof to the floor for the present cut. This system provides a signal to control a constant depth of cut. The last cut follower mechanism continually monitors the distance from the mine roof of the prior cut to the cutting drum. This latter system provides a signal to minimize the step height in the roof between cuts. The referencing system, which includes the last cut follower, LCF, mechanism and the rear drum referencing mechanism, RDRM, is designed to be operated manually and it is to be adapted to interface with a system which automatically controls the drum position. These two mechanisms are to be stowable and deployable automatically.

Signals from the two sensors are visually displayed by pointers on linearized scales to indicate the desired change in height of the cutting drum. The two mechanisms use mechanical probes which are actuated by hydropneumatic springs. The dynamic response of this hydraulic-pneumatic and mechanical system is analyzed to determine accumulator size and precharge pressure.

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NOMENCLATURE

SYMBOL	DESCRIPTION
A	Area, IN^2
a_1	Distance as shown in Figure 2.12, IN
a_2	Distance as shown in Figure 2.12, IN
C	Nominal Height of Deployed Probe, IN
d	Length of drive arm between its rotating center and cable head, IN
ds	Diameter of shear pin, IN
d_i	Inside Diameter, IN
d_o	Outside diameter, IN
e	Length of drive arm between its rotating center and piston rod end
F	Shearing force, LB
F_R	Probe contact force, LB
f	Length between gravity center and rotating center of link, IN
I	Mass moment of inertia, $LB\text{-}IN\text{-}SEC^2$
P	Pressure, PSIA
S	Length of arm as shown in Figure 2.10, IN
T	Tension in Cable, LB
V	Volume, IN^3
W	Weight of a member, LB
X	Piston displacement, IN
y	Vertical displacement of probe, IN
τ	Shearing stress, PSI

NOMENCLATURE (Continued)

SYMBOL	DESCRIPTION
θ	Angle between probe arm and its nominal position, DEGREES
α	Angle between arms as shown in Figure 2.10, DEGREES
β	Angle between arm and horizontal line as shown in Figure 2.10, DEGREES
4	Drive arm angle when piston is fully extended to hear end, DEGREES
ϕ	Angle locating position of drive arm as shown in Figure 2.11, DEGREES
γ	Nominal position of drive arm with respect to vertical line, DEGREES

CHAPTER I

INTRODUCTION

Energy! Americans will long remember those winter mornings in 1975, waiting for gasoline in the freezing dawn. Nor will millions of cold Americans easily forget the winter of 1976-1977 and those drastically lowered thermostats. Consider the natural sources of energy that are continually present in our midst, sources that would provide unending power...water, solar, nuclear and fossil fuel. For many years the most economical energy sources were natural gas and crude oil. But these are rapidly being depleted by the industrial nations. The severity of the shortage of world wide crude oil can be better realized when it is noted that more oil has been consumed in the last 25 years than in all previous years in history. At this rate, the present known resources of crude oil will be completely exhausted by the year 2000. Nuclear and solar energy appear to need long range research before they can be economically applied on a large scale with minimum pollution. Thus, the world wide demand for energy has led to the "rediscovery of coal" - the once and future king (1).

It has been estimated that a threefold to fivefold increase in world coal production must occur during the next 40 years to meet increasing energy requirements. Therefore, a big step forward in mining technology, particularly in remote control, automation and monitoring to achieve greater safety and productivity, is greatly needed. This is why the Bureau of Mines (BOM) has introduced the longwall shearer mining technique from Europe and is studying

the possibility of installing remote controls to increase safety and productivity.

Widely used in Europe, the longwall mining technique was introduced into the United States in 1960. Since then, the longwall mining technique has been improved and is becoming more popular. There are three major advantages to this technique. One advantage is higher recovery rates. Recovery of up to 80% of the coal is presently obtainable while the BOM reports possible recovery of up to 90%. This is well above the current recovery rate of 55% for the average room and pillar mining technique. The second advantage is high productivity because of an inherently new mining technique and high cutting speed. The third advantage is the improvement of health and safety factors in the mine. The problems with weak mine roofs are overcome and ventilation of the working area is improved also (2).

A specific type of longwall mining, known as the longwall shearer (LWS) method, is being studied by the BOM. There are basically three main parts to the LWS (Figure 1.1): the main frame; the hydraulic roof supports; and a conveyor system. The LWS is moved along tracks. As it advances, coal is sheared by two rotating drums (Figure 1.2). The cutting teeth on each drum form a helix so that loose coal is moved onto the conveyor belt between the LWS tracks (Figure 1.3) while the drums are in operation. After the cutting drum passes the roof supports, these supports are moved forward 30 inches, which is the width of cut. As the roof supports progress, the overburden causes a cave-in of the nonsupported roof. By using this operating process, the LWS system is able to progress

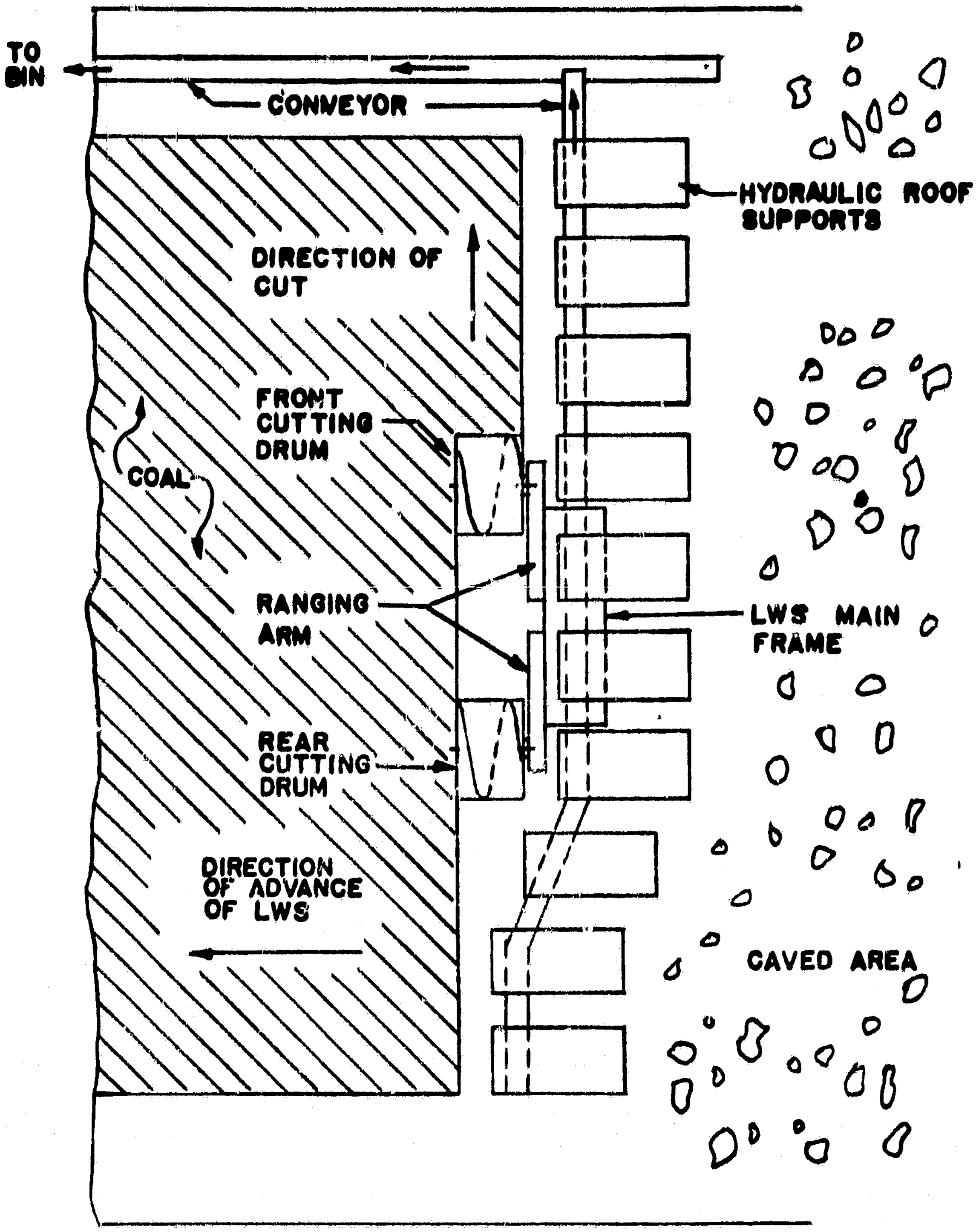
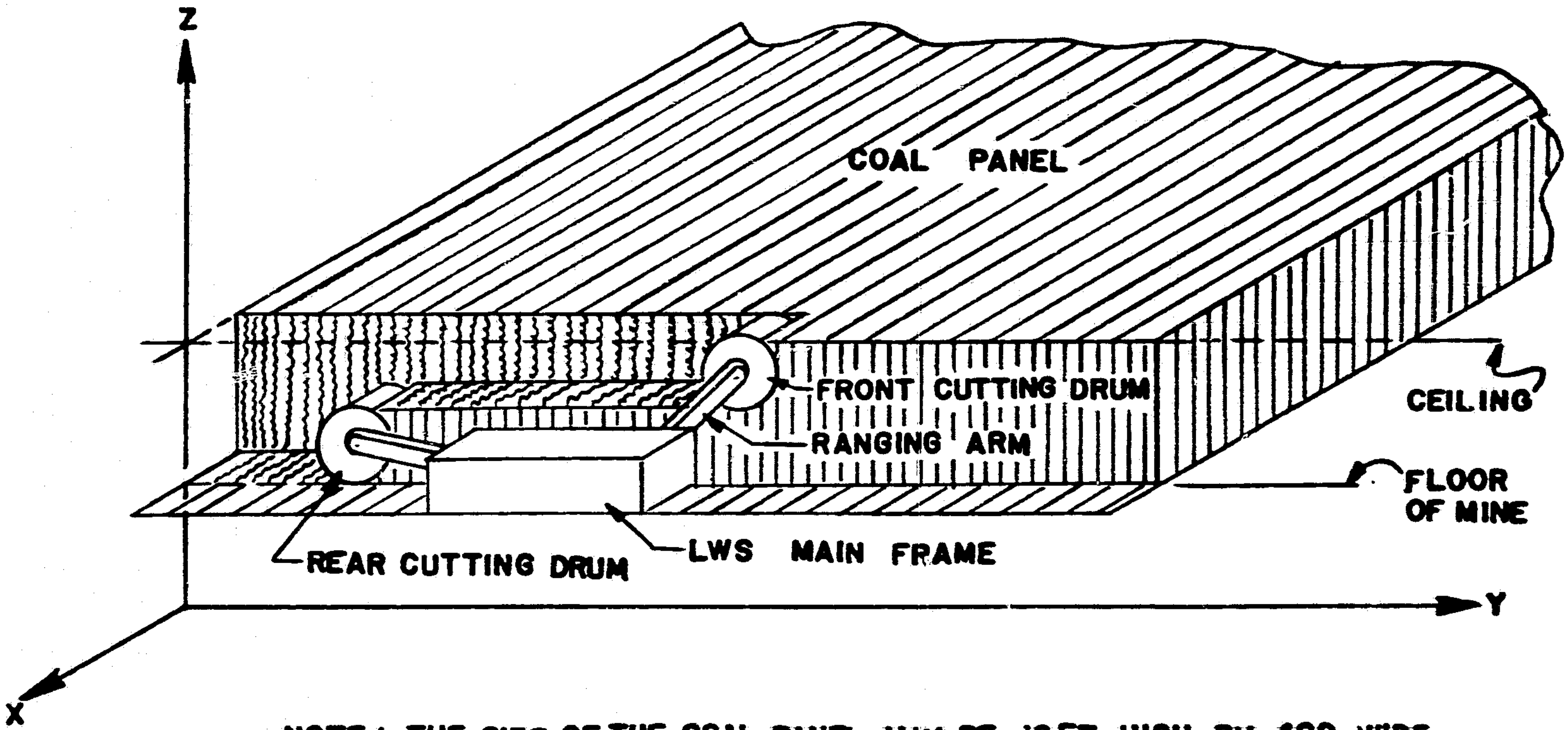


FIGURE 1.1 METHOD OF LONGWALL SHEARING



NOTE : THE SIZE OF THE COAL PANEL MAY BE 10 FT HIGH BY 400 WIDE AND 1000 FT LONG. CONVEYOR FOR TRANSPORTING COAL IS NOT SHOWN.

FIGURE 1.2 LONGWALL SHEARER IN OPERATION

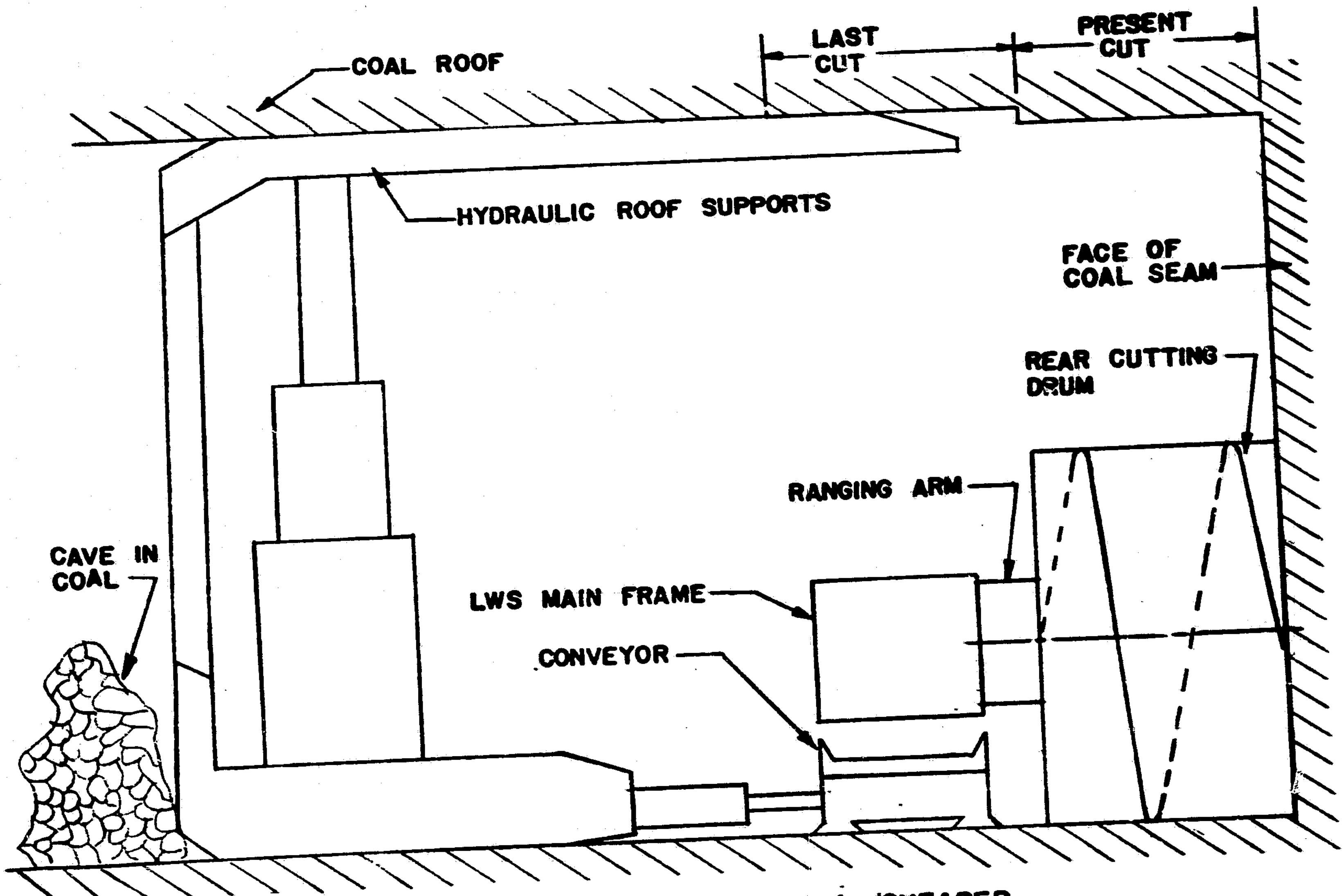


FIGURE 1.3 SIDE VIEW OF LONGWALL SHEARER

along the coal seam properly as it repeatedly shaves off a 30 inch wide slice along the 300 to 600 foot long face of the seam.

At present, a man is needed to control the vertical position of each cutting drum. However, the depth of coal remaining on the mine roof after a cut may be remotely measured by a Nucleonic Coal Interface Detector (3). Hence, the use of a Nucleonic Coal Interface Detector, CID, could allow the LWS to follow the undulating surface of a mine. Some studies have indicated that the depth of a coal seam does not vary more than a couple of inches over long distances, even though the seam may have undulations as it follows the earth's crust. Therefore, it appears feasible to design a rear drum referencing mechanism (RDRM) which will make contact with the mine roof and provide an error signal proportional to the deviation of the depth of cut from the mean height of the seam. Thus, the CID and RDRM would provide vertical guidance for the automated LWS. A last cut follower (LCF) would provide another useful signal for vertical control of the automated LWS because it could provide a signal which indicates the difference between the roof surface at the present cutter path and the roof surface at the adjacent last cut. This signal could be used to prevent excessive steps between adjacent cuts in the roof. The National Aeronautics and Space Administration, NASA, is working with the BOM, to automate the LWS (4).

Since the CID has been designed and built, the next step is to design the RDRM for referencing the rear drum of the LWS to the roof surface. The main idea of this referencing system is to use a probe, which slides along the roof of the cutter's current path, to give the information on the depth of the present cut. Also, the LCF is

designed to slide along the mine roof in the previous cut. This will provide a signal which is proportional to the deviation of the roof top between the current cut and the prior cut.

The purpose of this thesis is to design, analyze and prepare detailed drawings of the RDRM and the LCF. The LCF will be deployed for the forward cutting drum and retracted for the astern cutting drum. The RDRM will be deployed for the astern drum and stowed for the forward drum.

The thesis will first discuss design concepts and the complete system design and will then analyze the system's dynamic response.

Seven concepts for the system are investigated but only two concepts are fully developed. The hydraulic system and dynamic response analysis of the RDRM are developed. The optimization of a 4-bar linkage in order to linearize the output of the sensors is also included.

CHAPTER II

DESIGN OF REAR DRUM REFERENCING SYSTEM

2.1 General Description

A rear drum referencing mechanism is designed to produce a control signal for the rear drum so the total depth of cut will remain constant even though the front drum may be following an undulating roof line. The RDRM is designed to withstand the severe mine environment. Because combustible gas is always a mine hazard, the complete system is actuated by hydraulic power instead of electrical power.

2.2 Functional Requirements

1. The rear drum is to follow a guide in such a manner that the total depth of cut remains constant even though the front drum may be following an undulating roof line.

2. A probe which actuates the guidance system is to contact the mine roof in the vicinity of the rear drum.

3. The guidance system output is to be a visible pointer which indicates the required change in drum height. The change in drum height is to be controlled manually. However, the design must be able to interface with a system which automatically controls the drum position.

4. The system is to be stowable and deployable automatically.

5. The system should be capable of relocation to measure the distance from the ceiling of the last cut to the front drum.

6. The system must be designed for operation in the severe environment of a coal mine.

7. The system is to be mounted on a Joy Longwall Shearer. It should be adaptable to other brands of Longwall Shearers.

2.3 Design Concepts

Several design concepts were investigated during the development of the system. The major difference between those concepts is the method of supporting the probe. These alternative concepts will be presented.

2.3.1 Alternative Concepts

The scissors type (Figure 2.1) arrangement can allow the probe to operate on the "last cut" beside the front drum or on the current cut" above the rear drum. The probe will move in a direction which is perpendicular to the main frame of the Longwall Shearer at all times due to the constraint of the parallel linkage.

The dual parallel linkage concept for supporting the probe (Figure 2.2) also holds the probe perpendicular to the main frame as in the first concept, but the parallel links are shorter to improve linkage stability and to provide more clearance for the hydraulic motor.

The multiple stage hydraulic cylinder concept (Figure 2.3) uses a rotary actuator to retract the mechanism. However, it would be difficult to prevent rotation between each stage of the telescoping cylinder.

The telescoping cylinder with guide tube concept (Figure 2.4) is a modification of the multiple stage cylinder concept except that it

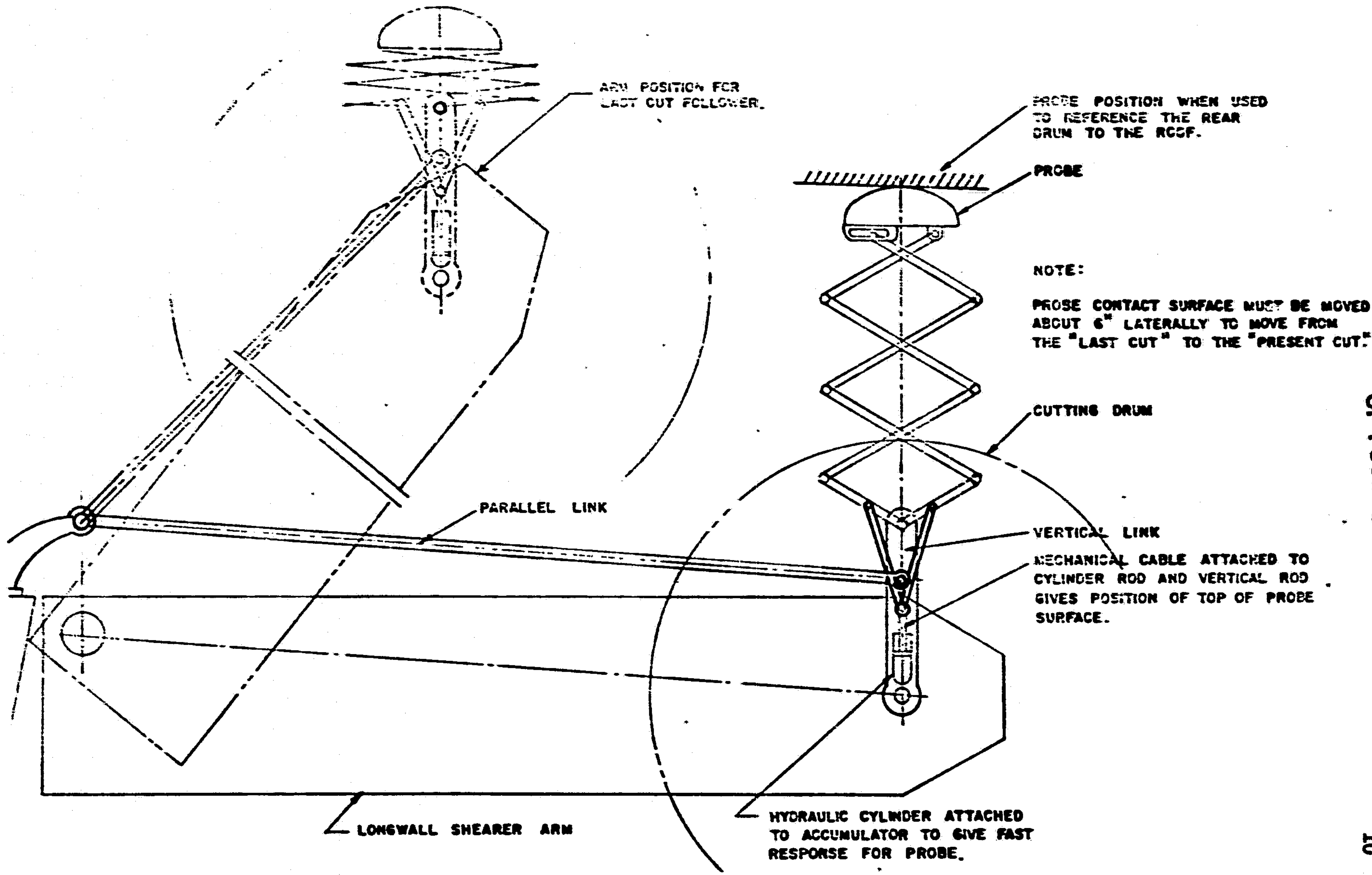


FIGURE 2.1 SCISSORS TYPE CONCEPT

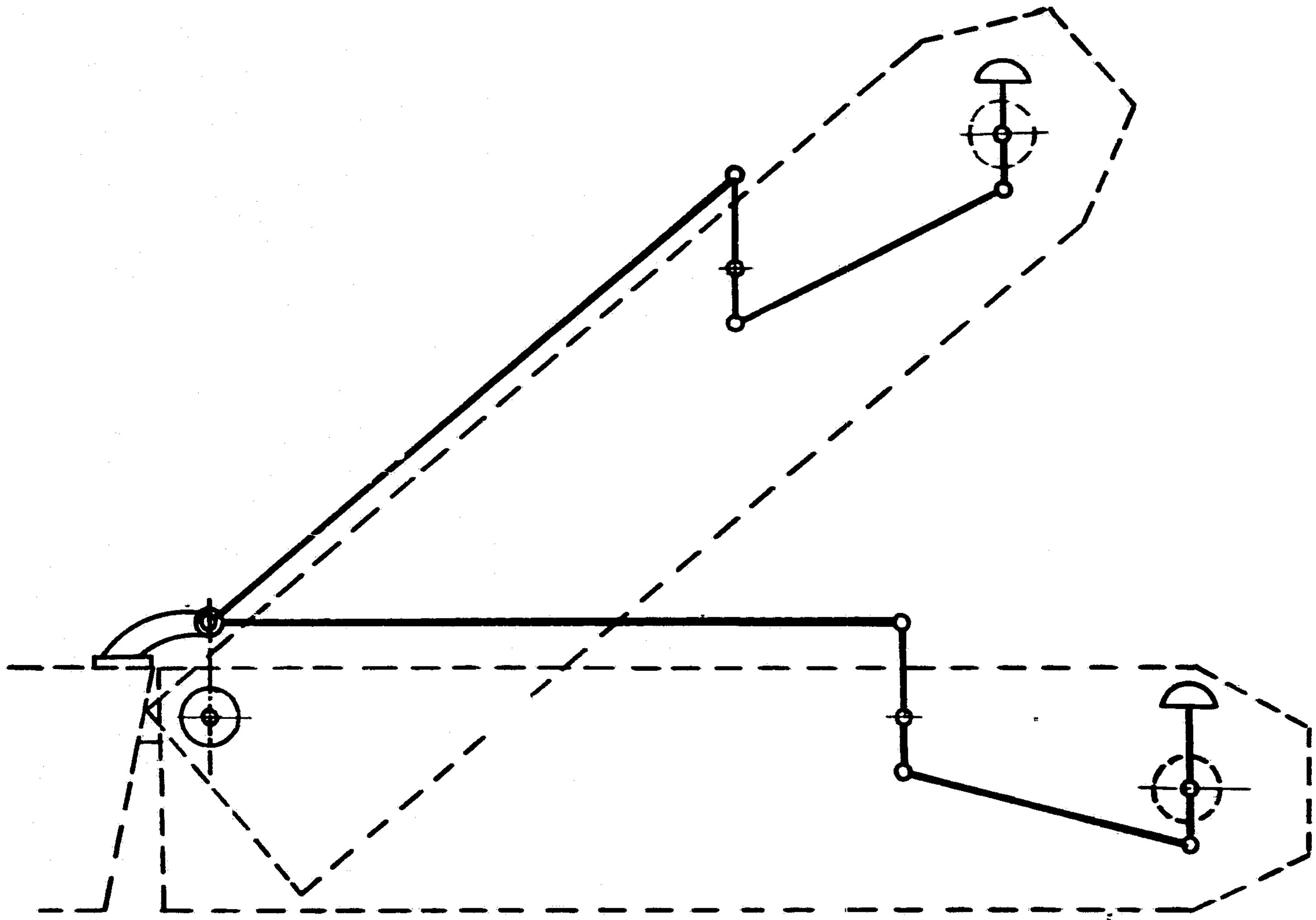


FIGURE 2.2 DUAL PARALLEL LINKAGE CONCEPT

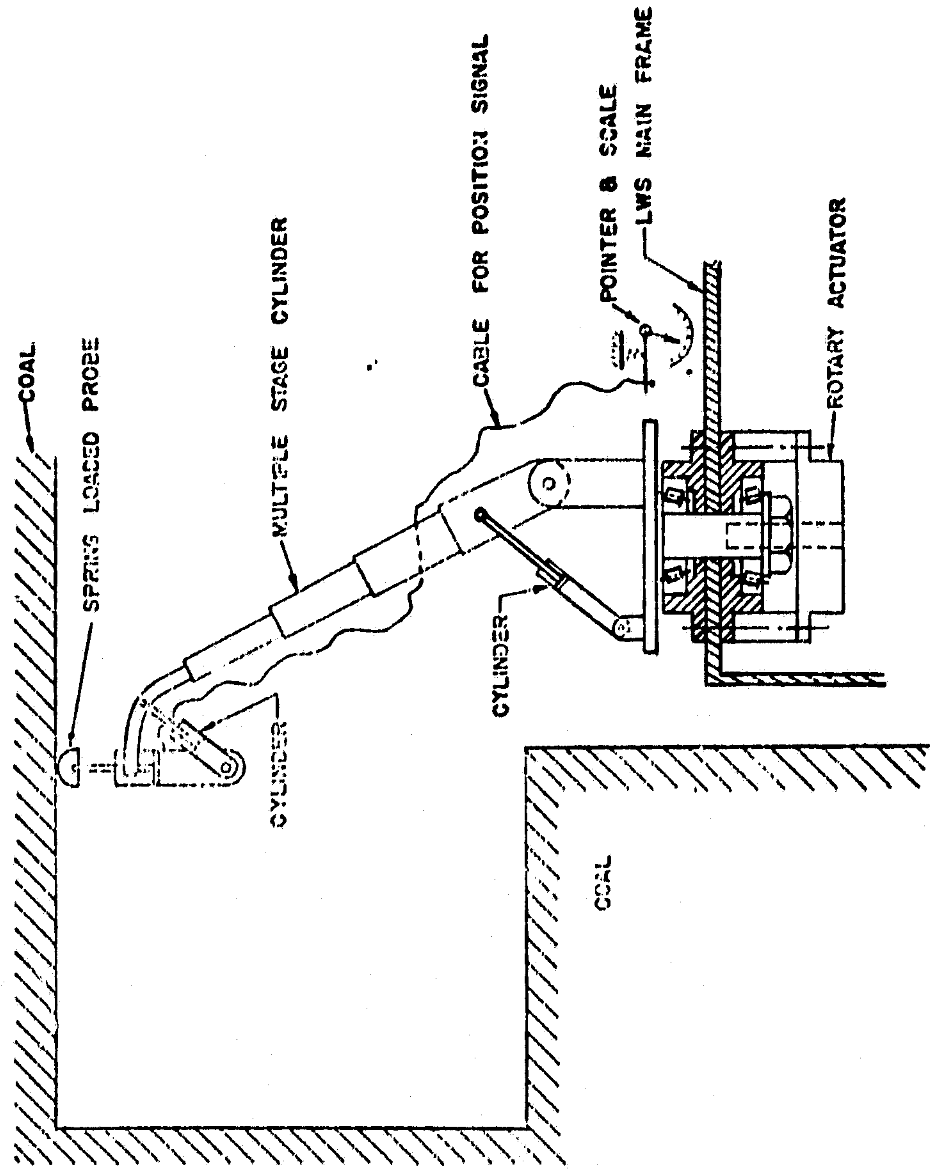


FIGURE 2.3 MULTIPLE STAGE CYLINDER CONCEPT

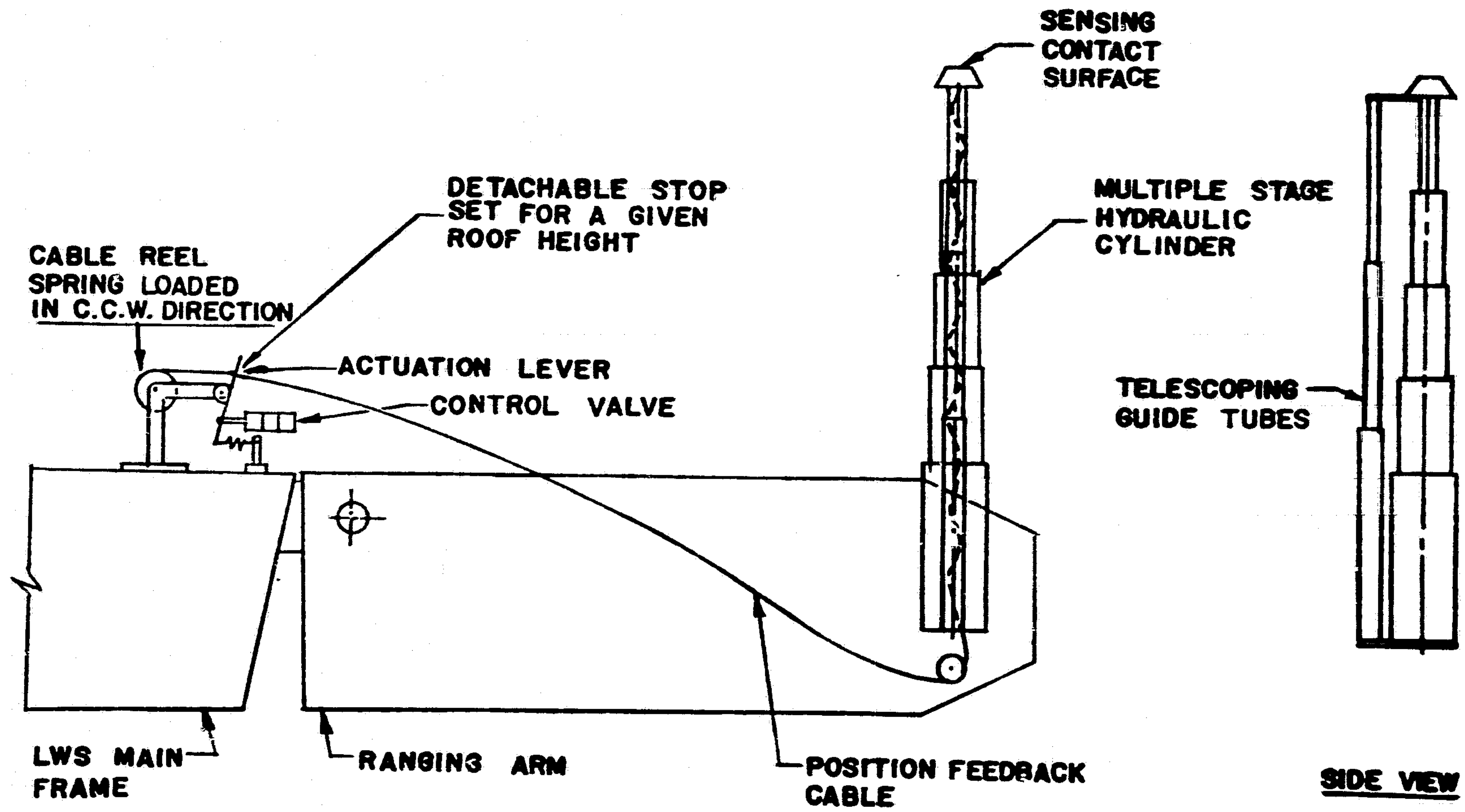


FIGURE 2.4 THE TELESCOPING GUIDE TUBE CONCEPT

is installed on the LWS arm with a guide tube to prevent telescoping cylinder rotation.

The single stage hydraulic cylinder concept (Figure 2.5) replaces the 4 stage telescopic cylinder concept. This concept will reduce the cost considerably, because the purchased items are standard and the hydraulic system is simplified. This concept was chosen for complete development.

2.3.2 The Final Concept

The concept which was selected for development is shown in Figure 2.5 and Figure 2.5A. This concept uses a single stage hydraulic cylinder to extend a telescoping rectangular tube. The outer telescoping tube is anchored to the LWS ranging arm by a pivot at the drum center and with adjustable turnbuckle. The turnbuckle provides correct angular positioning to place the probe directly over the cutting drum center for various coal seam heights and sizes of cutting drums. This turnbuckle adjustment should work for constant depth coal seams but not for variable seam thicknesses.

The probe surface which rides on the coal roof is on an arm which is pulled up against the roof by a cable. The tension in the cable is approximately constant as it is provided by a hydraulic cyclinder pressurized by an accumulator which will be described in the next section. A general outline of the final design is shown in Figures 2.5 and 2.5A.

The rectangular two stage telescoping mechanism used in the RDRM is illustrated in Figure 2.6. The inner rectangular tube is pushed up by the hydraulic cylinder when it is pressurized by the hydraulic

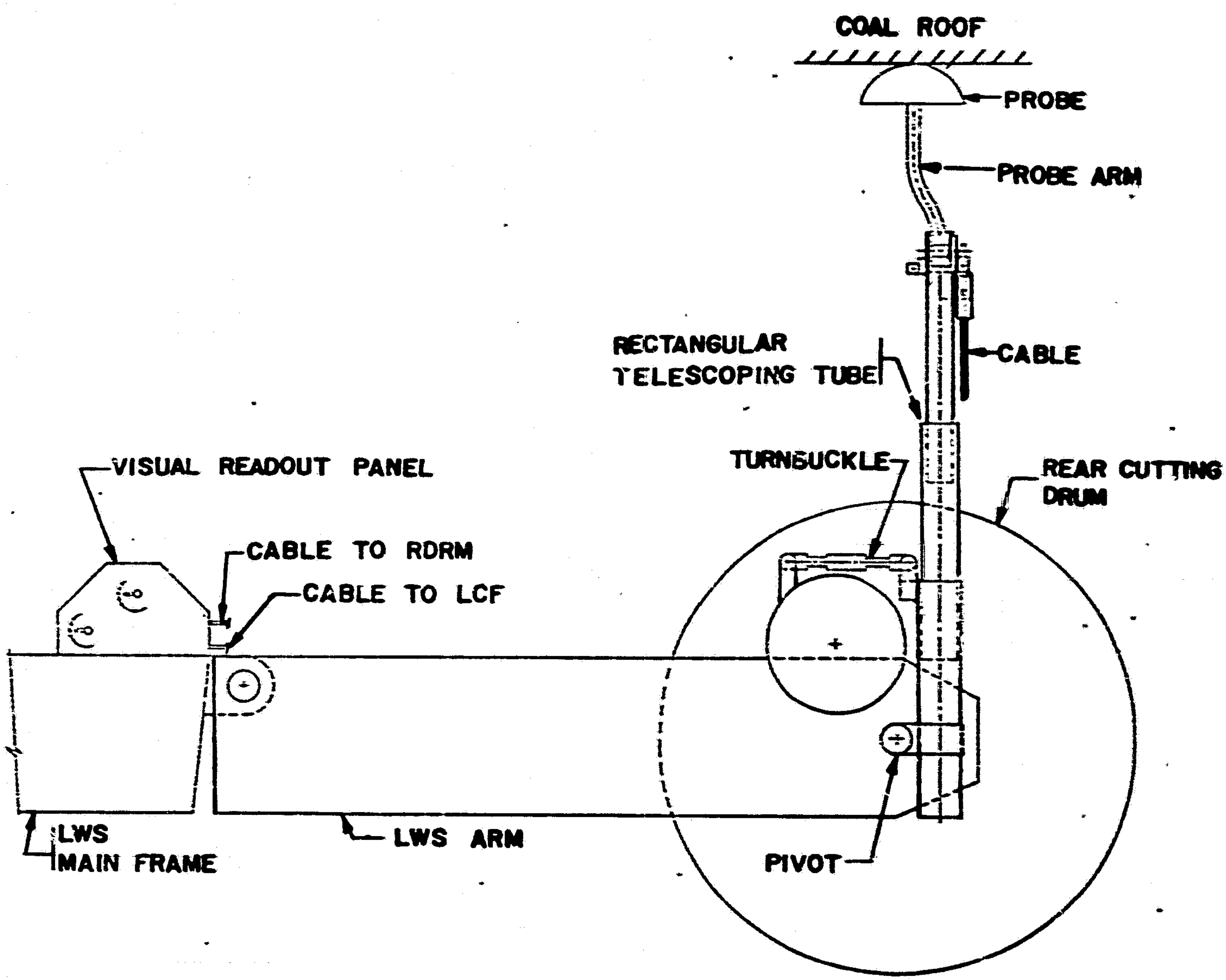


FIGURE 2.5 GENERAL OUTLINE OF RDRM (FRONT VIEW)

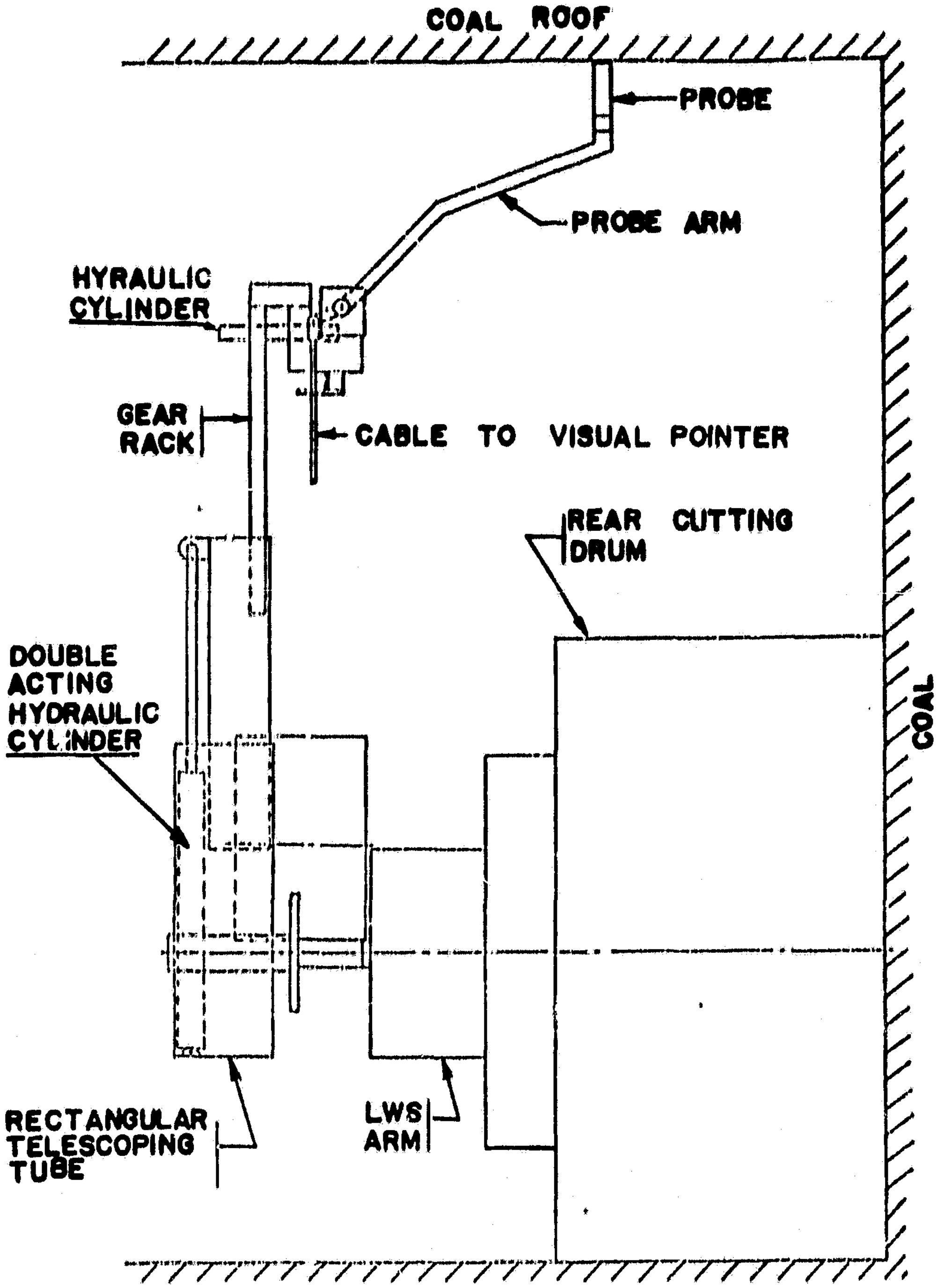


FIGURE 2.5 A GENERAL ARRANGEMENT OF RDRM (SIDE VIEW)

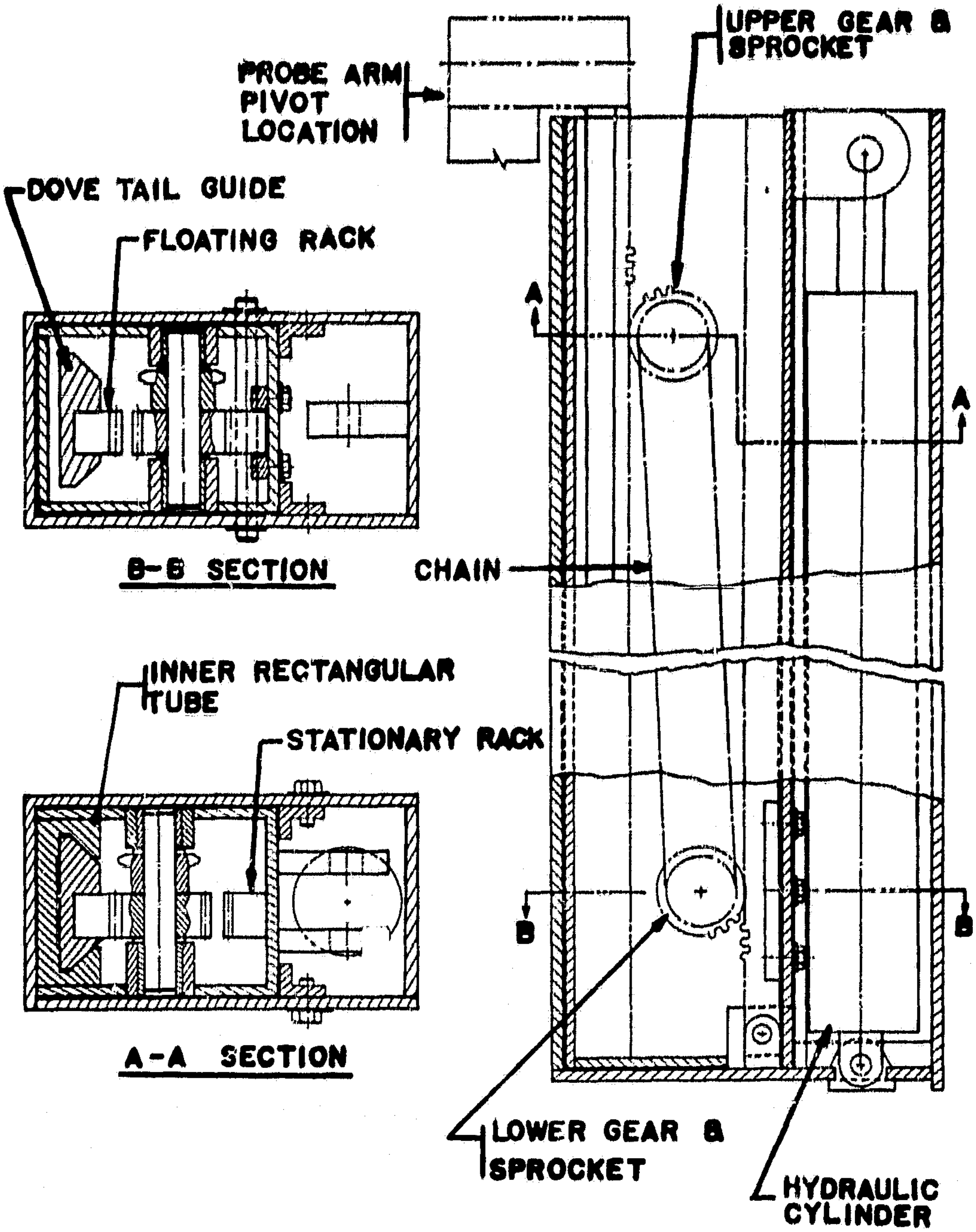


FIGURE 2.6 RECTANGULAR TELESCOPING MECHANISM

valve. As the inner rectangular tube moves up, it rotates the spur gears and the chain sprocket because the spur gear is engaged with the rack which is fixed to the outer rectangular tube. The lower sprocket drives the upper sprocket and the upper spur gear via the chain. As the upper spur gear rotates, it will drive the floating rack upward in the inner rectangular tube. A hydraulic actuator and pivot assembly (Figure 2.6A) are mounted on the top of the floating rack. The actuator can rotate the probe 90 degrees for the storage position.

The visual readout of the drum height correction required for maintaining a constant depth of cut is provided by a pointer which gives a linear readout from the nonlinear signal of the probe. The probe transmits the signal to the 4-bar linkage by a cable. The general arrangement of 4-bar linkage is shown on Figure 2.7.

When the whole mechanism needs to be retracted, the first step is to change the 4-way valve position so that the double acting cylinder can pull the inner rectangular tube and the modified rack down. A second hydraulic valve is actuated to rotate the probe arm 90 degrees into the storage position.

Because of the long probe arm, an aluminum tube is used to reduce mass and to obtain a quick response time. Zinc dichromate primer should be used prior to applying finish coats to avoid galvanic action between steel and aluminum.

2.3.3 Hydraulic Circuits

There are three hydraulic circuits to operate the system. The purpose of the vertical positioning circuit is to raise or lower the pivot of the probe for different average coal seam thicknesses. As

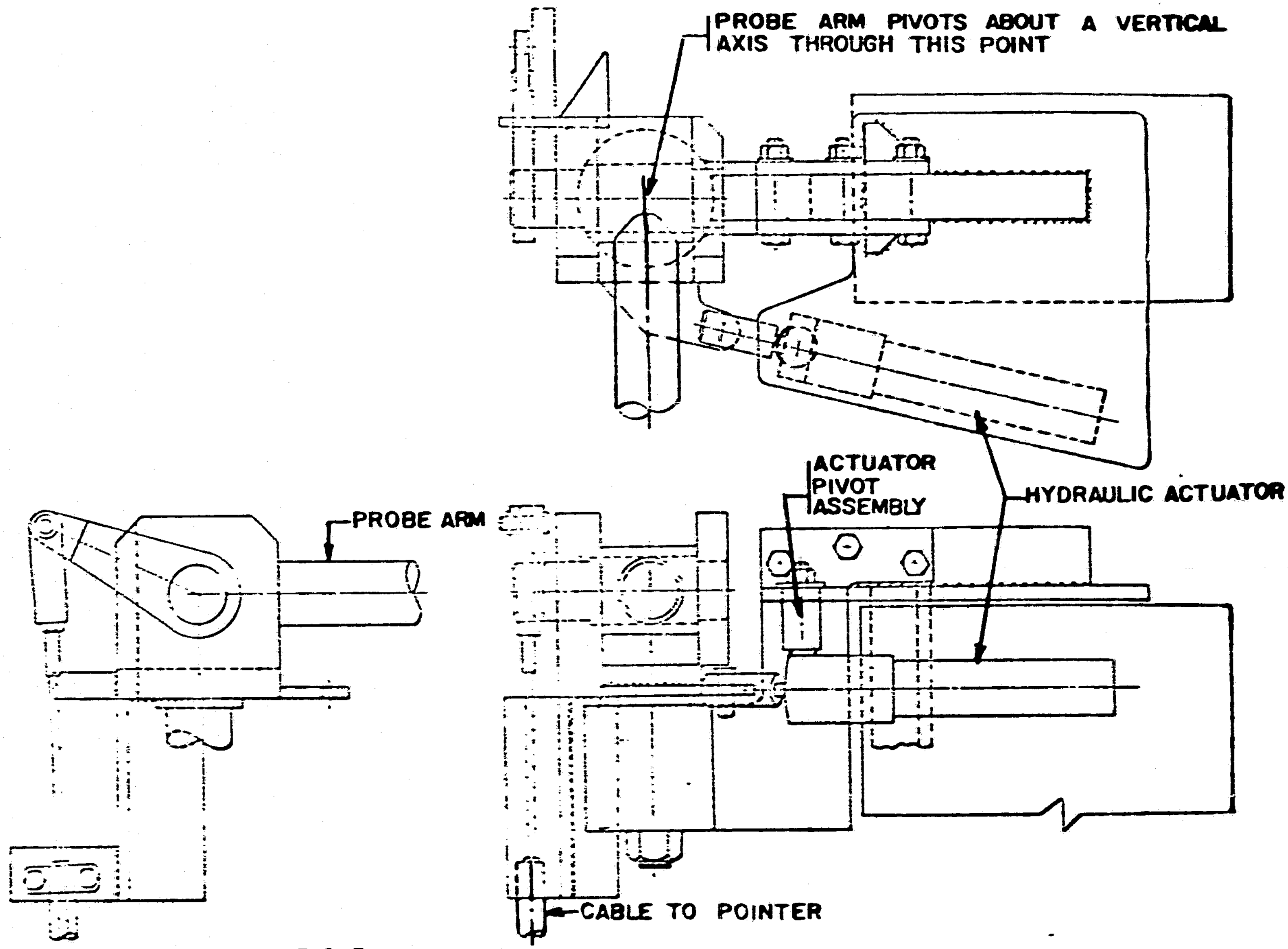


FIGURE 2-6A HYDRAULIC ACTUATOR AND PIVOT ASSEMBLY

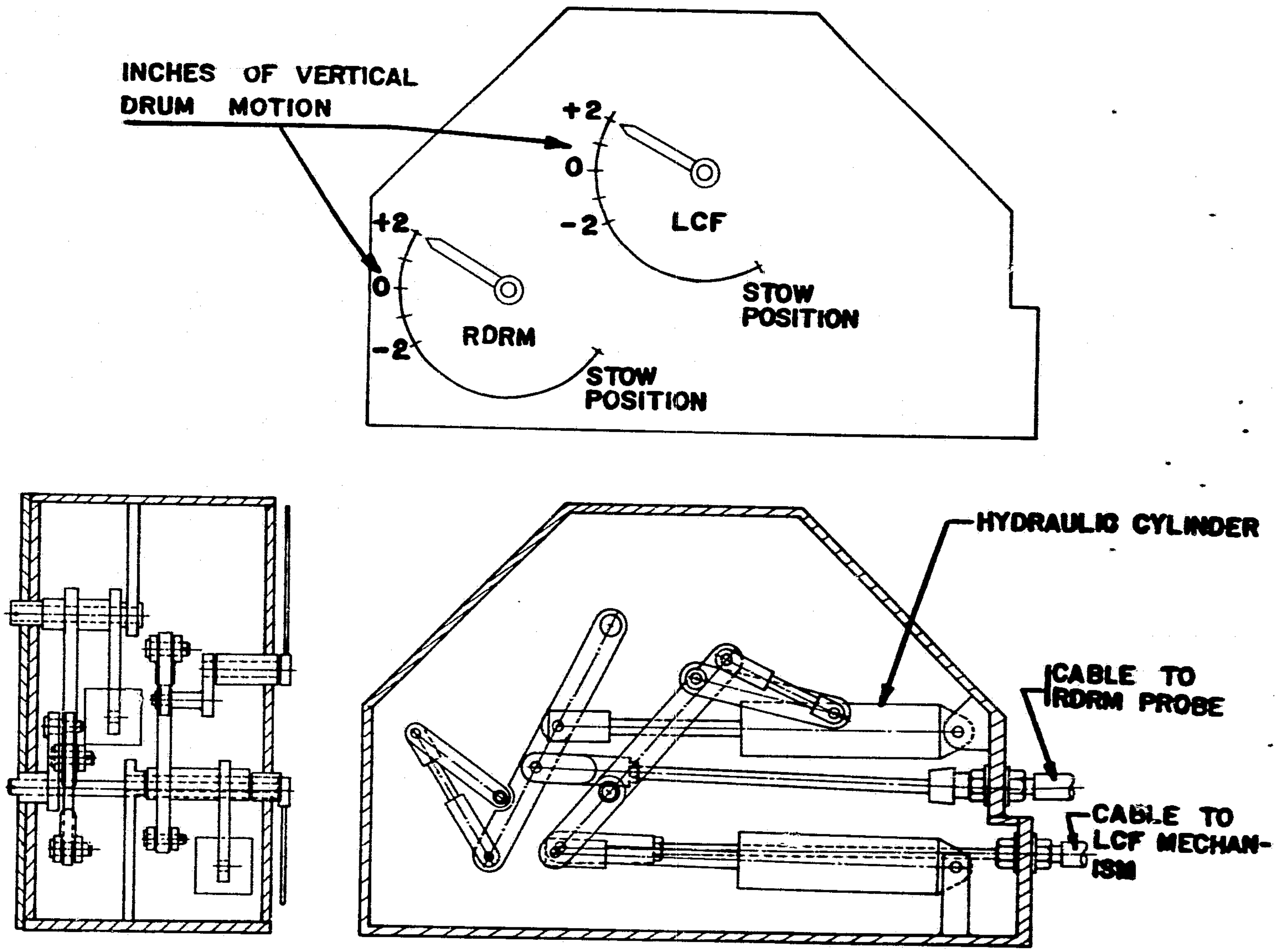


FIGURE 2.7 LINEARIZED FOUR-BAR LINKAGE ARRANGEMENT

can be seen in Figure 2.8, a 3 position 4-way control valve regulates the oil supply to the cylinder for the purpose of raising or lowering the probe by way of the gear rack, gears and chain as shown in Figure 2.6. The relief valve is used as a safety device in case of a roof cave-in. The sensing circuit provides approximately a constant force between the probe and roof of the mine by the cable which connects the probe arm to the visual readout linkage. This constant force is obtained by using an accumulator for the hydraulic supply. The arm may be lowered by reversing the actuation cylinder in this sensing circuit.

The angular deployment circuit controls the probe arm position. The arm can be positioned normal to the direction of travel for the active position or the probe arm may be positioned parallel to the direction of travel for the stow position. The circuits will use the same source of oil as the LWS. Pressure reducing valves are used to obtain the required pressure.

2.3.4 Overload Devices

A shear pin is provided to prevent damage due to a frontal force acting on the RDRM. Located at the top of the telescoping rectangular tube adjacent to the turnbuckle, this hollow shear pin should shear at a load of 5000 lbs which is much lower than the load which would fail the axle pivot. The shear pin is made of SAE 1018 CFS material which has a tensile yield stress of approximately 56000 PSI and a shearing yield stress of 0.577*56000PSI. Thus, the diameter of shear pin, d, is

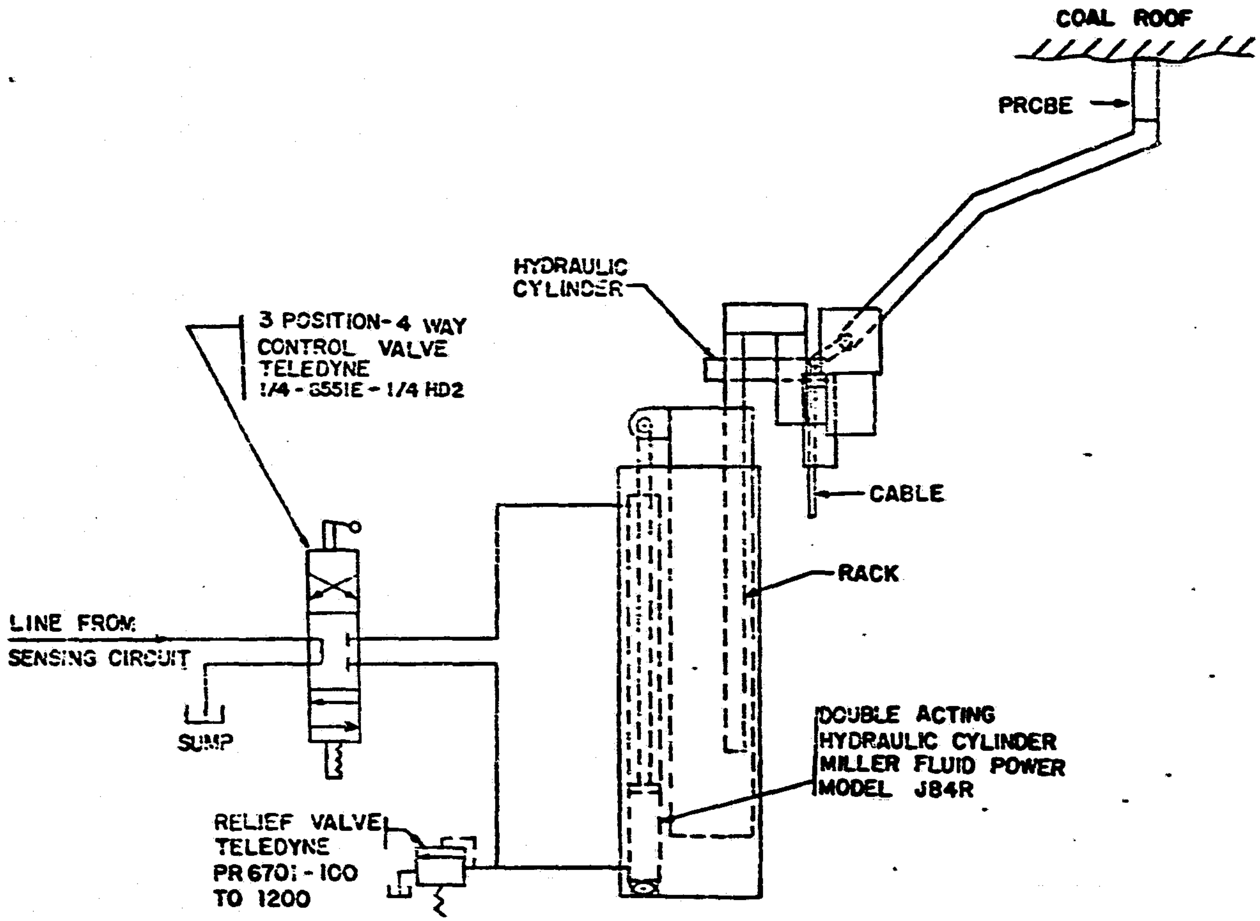


FIGURE 2. 8 VERTICAL POSITIONING CIRCUIT FOR DIFFERENT ROOF HEIGHTS (REAR DRUM REFERENCING MECHANISM)

$$\tau = \frac{F}{2A} = \frac{5000}{2(\pi/4)d^2} = 0.577*56000 \text{ PSI}$$

$$d = 0.313 \text{ INCH}$$

Since the pin diameter is small, the bearing stress will be high. Hence, it is better to use a hollow pin instead of a solid pin. If we assume the wall thickness is 0.0625 inch, then

$$d_o = d_i + 0.0625 * 2$$

where

d_o = outside diameter of pin

d_i = inside diameter of pin.

The shear area of the solid pin must be equal to the shear area of the hollow pin. Therefore

$$\pi/4 * (0.313)^2 = \pi/4 *(d_o{}^2 - d_i{}^2) \text{ .}$$

Hence

d_i = 0.337 inch

d_o = 0.462 inch.

The relief valve and accumulator in the hydraulic system also serve as safety devices. The accumulator provides the hydropneumatic spring for the probe arm. Thus, when an excessive vertical load is applied to the probe, such as during a mine roof cave-in, the accumulator allows the probe to move down to the bottom of its travel. If the excessive vertical loads continue, the relief valve will be actuated to allow the rectangular telescoping mechanism to collapse also.

2.3.5 Dynamic Response of Rear Drum Referencing Mechanism

The dynamic response of the RDRM probe is investigated to establish a design which will maintain contact at the coal roof. The following parameters are determined from the dynamic study: (1) accumulator size; (2) inertia of probe arm; (3) precharge pressure of accumulator.

There are three hydraulic circuits: a vertical positioning circuit for different roof cuts, an angular deployment circuit for stowing the probe, and a sensing circuit which drives the deployed probe. The first circuit controls the various heights of a rectangular telescoping mechanism for different cutting drum diameters and coal roof heights. This circuit is controlled by a double acting hydraulic cylinder with a maximum stroke of 18 inches and a three-position-four-way control valve as shown in Figure 2.8. The second circuit rotates the probe arm 90 degrees when the rear drum referencing mechanism is deployed and stowed per Figure 2.9. The sensing citcuit exerts a steady force on a cable to pull the probe against the roof surface when the probe is in the active position. This

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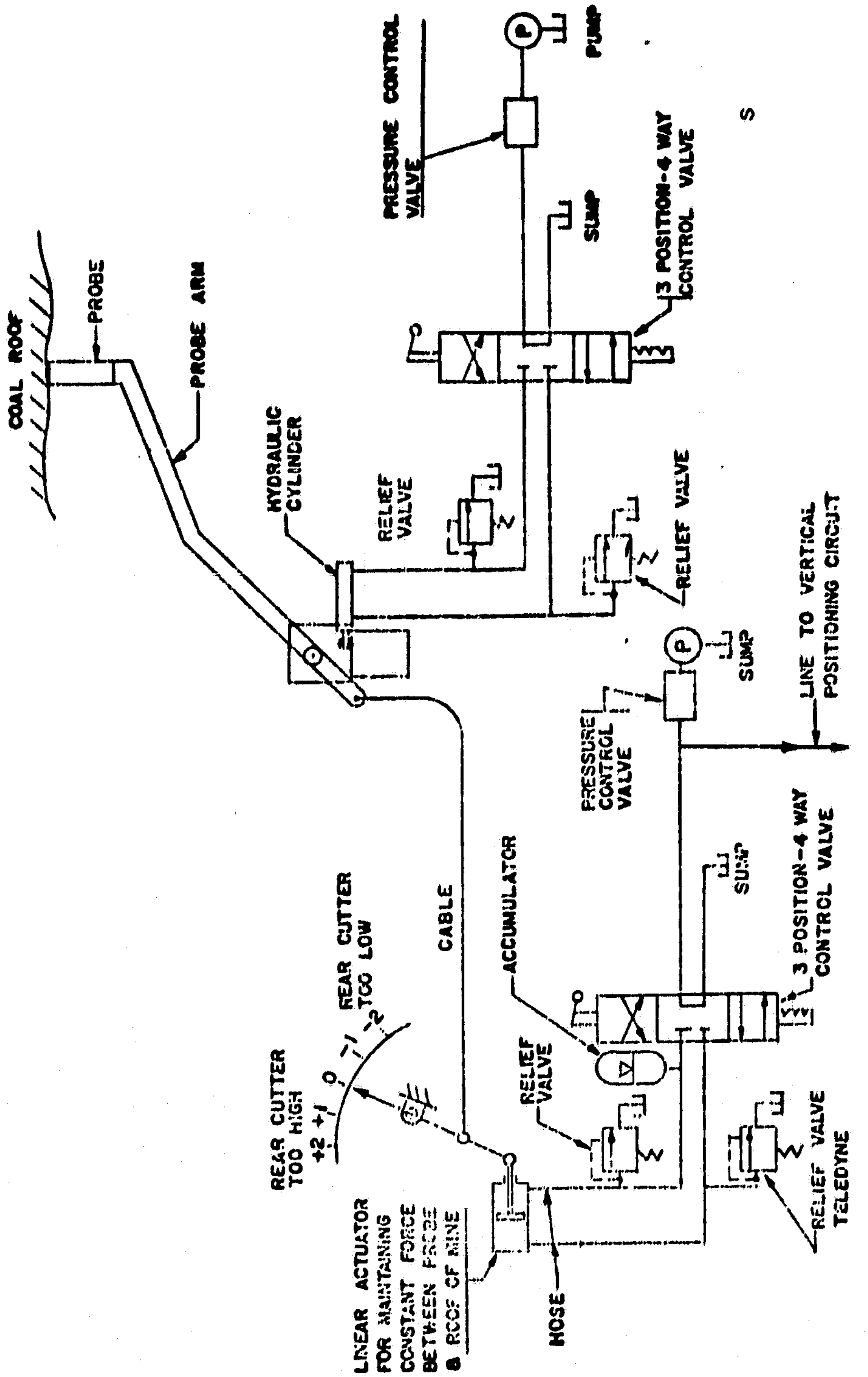


FIGURE 2.9 ANGULAR DEPLOYMENT CIRCUIT FOR PROBE & SENSING CIRCUIT
(REAR DRUM REFERENCING MECHANISM)

circuit is shown in Figure 2.9. The existing hydraulic system on the LWS will serve as the source of pressurized hydraulic oil for these three circuits. Pressure control valves are installed in each circuit to provide the required pressures.

A mathematical model of the hydraulic system will aid in the determination of required pressures, capacity of accumulator needed to obtain the desired response time, angular velocity of probe arm rotation, and contact pressure between probe and coal roof.

Only the dynamic system of the sensing circuit which drives the deployed probe will be analyzed. Because it consists of a long arm and heavy probe, the system was simplified as shown in Figure 2.10 and 2.11 for mathematic formulation.

The moment about the pivot for the system in Figure 2.10 may be written as

$$+\circlearrowright \Sigma M_o = I\ddot{\theta}$$

$$- F_R\, a \cos(\beta + \theta) - w_2\, b \cos(\beta + \theta) - TS \cos(\alpha - \beta - \theta) = I_2\ddot{\theta} \;.$$

But,

$$\cos(\beta + \theta) = \cos\beta \cos\theta - \sin\beta \sin\theta$$

$$\cos[(\alpha - \beta) - \theta] = \cos(\alpha - \beta) \cos\theta + \sin(\alpha - \beta) \sin\theta$$

Hence,

$$- F_R\, a \{\cos\beta \cos\theta - \sin\beta\sin\theta\} - w_2 b$$

$$\{\cos\beta \cos\theta - \sin\theta\sin\beta\} - TS\{\cos(\alpha - \beta) \cos\theta +$$

$$\sin(\alpha - \beta)\sin\theta\} = I_2\ddot{\theta} \;.$$

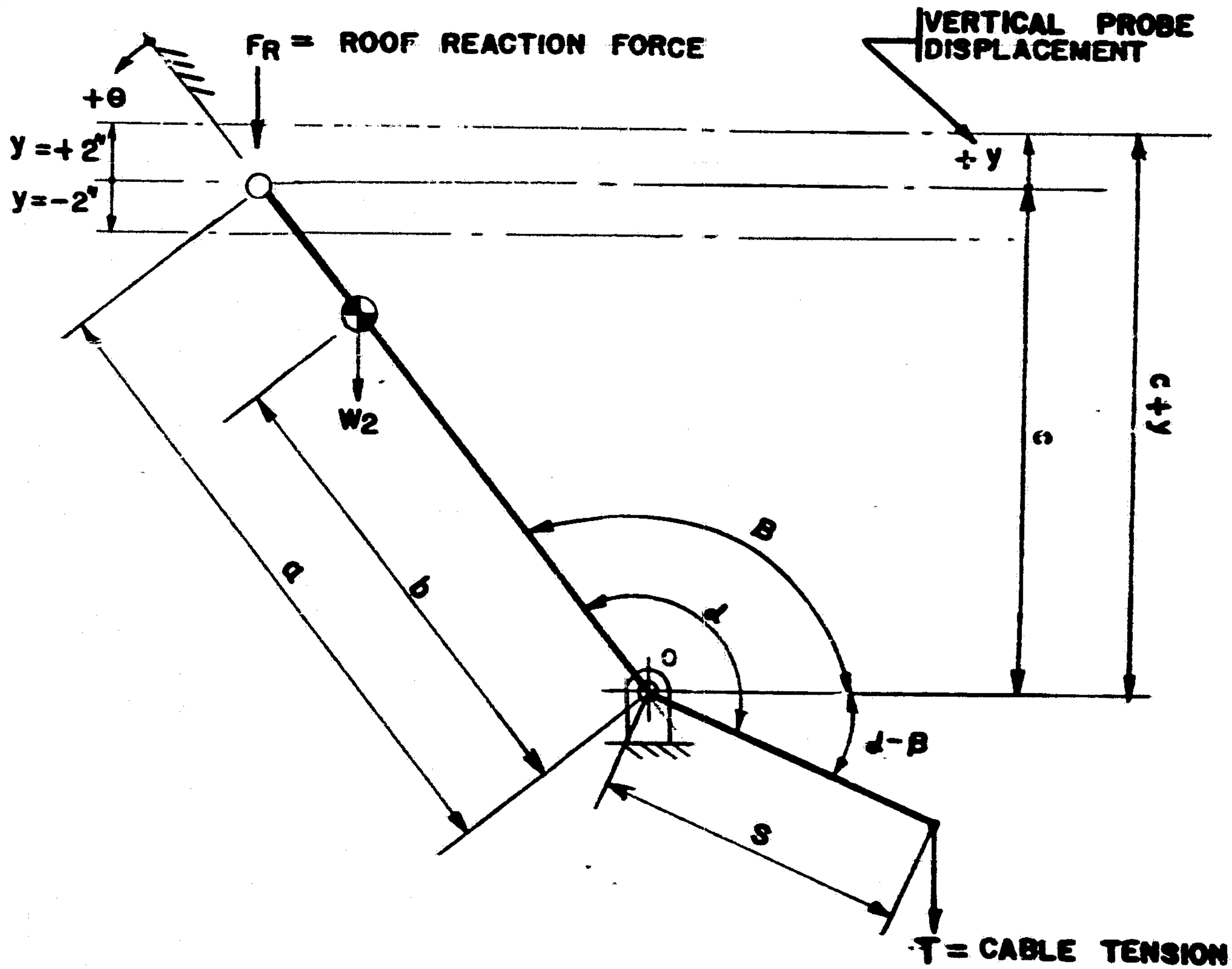


FIGURE 2.10. SCHEMATIC OF FORCES ACTING ON RDRM PROBE ARM

For small angles,

$$\cos\theta \approx 1$$

and

$$\sin\theta \approx \theta .$$

Therefore,

$$-F_R\, a \cos\beta - w_2 b \cos\beta - TS\cos(\alpha-\beta) + \theta\{F_R\, a \sin\beta$$

$$+ w_2 b \sin\beta - TS\sin(\alpha-\beta)\} = I_2\ddot{\theta} ,$$

or,

$$\ddot{\theta} - \theta\left\{\frac{F_R\, a \sin\beta}{I_2} + \frac{w_2\, b \sin\beta}{I_2} - \frac{TS\ \sin(\alpha-\beta)}{I_2}\right\} +$$

$$\left\{\frac{F_R\, a \cos\beta}{I_2} + \frac{w_2\, b \cos\beta}{I_2} + \frac{TS\ \cos(\alpha-\beta)}{I_2}\right\} = 0 ,$$

or,

$$\ddot{\theta} - \theta C_1 + C_2 + T\,(C_3 + \theta\, C_4) = 0 \qquad (2.1)$$

where,

$$C_1 = \frac{F_R\, a \sin\beta}{I_2} + \frac{w_2\, b \sin\beta}{I_2}$$

$$C_2 = \frac{F_R\, a \cos\beta}{I_2} + \frac{w_2\, b \cos\beta}{I_2}$$

$$C_3 = \frac{S\cos(\alpha-\beta)}{I_2}$$

$$C_4 = (S\sin(\alpha-\beta))/I_2 .$$

The cable tension (T), which provides the accelerating force in Equation 2.1, is developed by the hydraulic cylinder and accumulator in Figure 2.11. The equation for pressure (P_2) and accumulator gas volume (V_2) is

$$P_2 V_2^n = C$$

or,

$$P_2 V_2^n = P_{ap} V_{ap}^n \quad .$$

The maximum volume of air for the accumulator is V_{max} and occurs when all oil is purged from the accumulator. This volume V_{max}, is pressurized with a pressure, P_{ap}, for an initial precharged state. Due to leakage from the system it is desirable to store some oil in the accumulator by pumping it in at a pressure, P_c, in excess of P_{ap}. The quantity of oil stored will be a function of P_{ap}, P_c and V_{max}.

$$(V_{max} - V_{oil}) = \left(\frac{P_{ap}}{P_c}\right)^{(1/n)} (V_{max})$$

If we select $V_{oil} = 3.5$ IN^3 and $n = 1.4$ for air, then,

$$P_c = P_{ap} \left(\frac{V_{max}}{V_{max} - 3.5}\right)^{1.4}$$

The hydraulic cylinder is fully extended under the above conditions of precharging with air and charging with oil. When the piston moves a distance, x, (Figure 2.11) the oil in the piston is forced

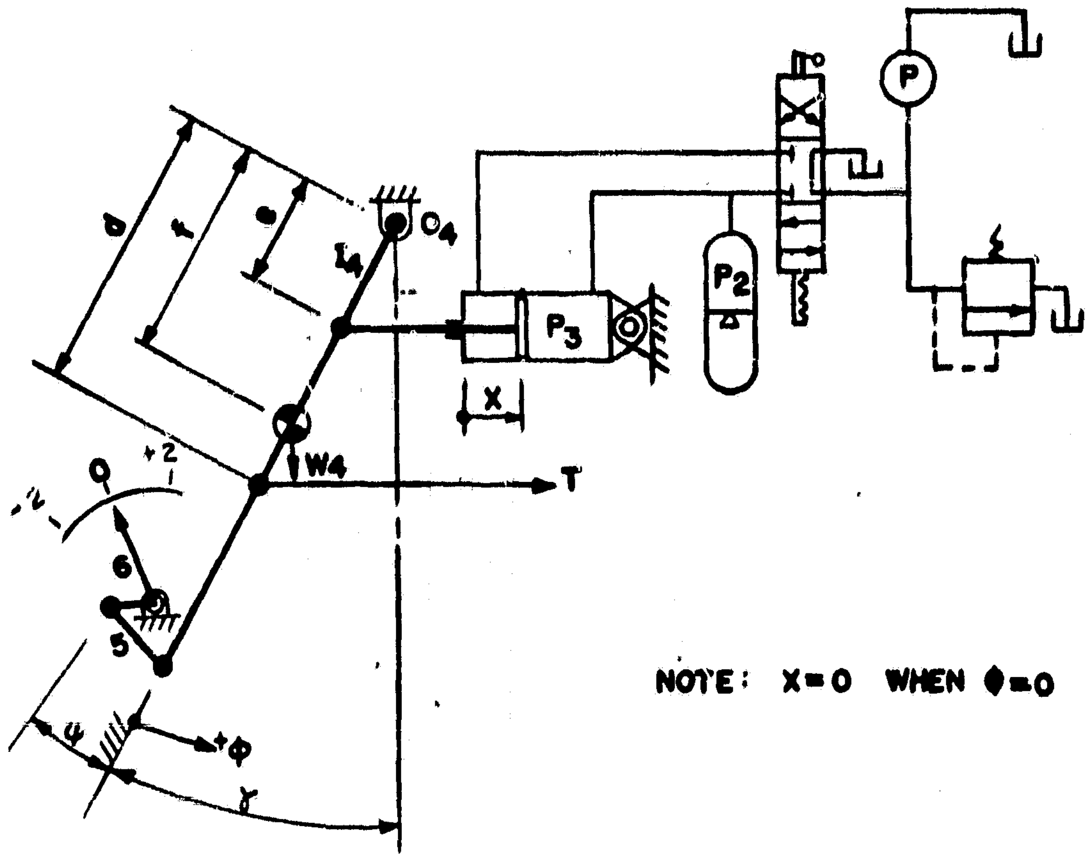


FIGURE 2.11 EQUIVALENT DYNAMIC SYSTEM OF LINEARIZED 4-BAR LINKAGE

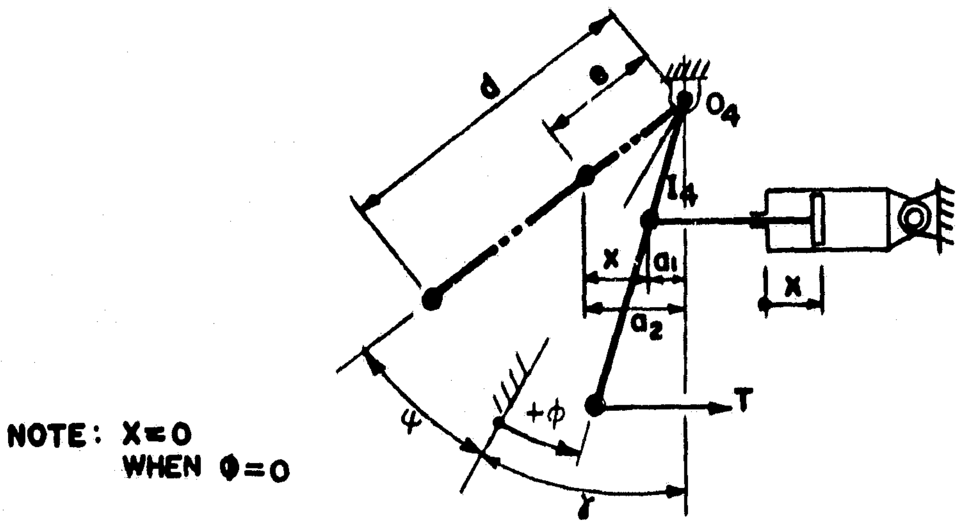


FIGURE 2.12 RELATION BETWEEN ANGULAR POSITION OF ARM and LINEAR POSITION OF PISTON

into the accumulator and the accumulator air volume is reduced by

$$\Delta V = x\ A_p$$

where,

$$A_p = \text{area of piston.}$$

Hence,

$$P_2 = P_{ap}\left(\frac{V_{max}}{V_{max} - 3.5 - x\ A_p}\right)^{1.4} .$$

The functional relationship between the piston displacement and the angular linkage movement is illustrated in Figure 2.12. The following derivation will result in an equation which expresses x as a function of the angles ϕ, γ, and ψ.

When

$$\phi = 0:\ \theta = 0,\quad y = 0,\ x \neq 0.$$

When

$$\phi = -\psi:\quad x = 0.$$

$$x = a_2 - a_1$$

$$a_1 = e\ \sin((\gamma + \psi) - (\psi + \phi))$$

$$a_1 = e\ \sin(\gamma - \phi)$$

$$a_2 = e\ \sin(\gamma + \psi)$$

Hence,

$$x = e\ \sin(\gamma + \psi) - e\ \sin(\gamma - \phi) \quad ;$$

but

$$\sin(A - B) = \sin A \cos B - \cos A \sin B\ .$$

For small angles

$$\sin \phi \approx \phi \quad \text{and} \cos \phi \approx 1.$$

Hence,

$$x = e\ \sin(\gamma + \psi) - e(\sin \gamma - \phi \cos \gamma\ ) \quad ;$$

but $\phi = S\ \theta/d.$

Thus,

$$x = e\ \sin(\gamma + \psi) - e\ \sin \gamma + \frac{e\ S\ \theta}{d} \cos \gamma$$

Let

$$B_9 = e\left[\sin(\gamma + \psi) - \sin \gamma\right]$$

$$B_{10} = \frac{S\ e\ \cos \gamma}{d}$$

Then

$$x = B_9 + \theta\ B_{10}$$

The moment about O_4 for the arm in Figure 2.11 may be simplified if the inertia of links 5 and 6 are neglected and if the moment due to the weight W_4 is neglected. The resulting free body diagram is shown in Figure 2.12.

$$+\circlearrowright \; \Sigma M = I_4 \ddot{\phi}$$

$$T\, d \cos(\gamma - \phi) - P_3 A_p\, e \cos(\gamma - \phi) = I_4 \ddot{\phi}$$

$$T\, d\{\cos\gamma \cos\phi + \sin\gamma \sin\phi\} - P_3 A_p\, e\{\cos\gamma \cos\phi$$

$$+ \sin\gamma \sin\phi\} = I_4 \ddot{\phi}\, .$$

For small angles,

$$\sin\phi \approx \phi \;\; ; \;\; \cos\phi \approx 1.$$

$$T\, d\{\cos\gamma - \phi \sin\gamma\} - P_3 A_p\, e\{\cos\gamma + \phi \sin\gamma\} = I_4 \ddot{\phi}$$

$$T = \frac{I_4 \ddot{\phi} + P_3 A_p\, e\{\cos\gamma + \phi \sin\gamma\}}{d\{\cos\gamma + \phi \sin\gamma\}} \, .$$

But

$$\ddot{\phi} = \ddot{\theta}\, \frac{S}{d} \, .$$

The pressure at any position, x, is:

$$P_2 = P_{ap} \left(\frac{V_{max}}{V_{max} - 3.5 - x A_p}\right)^{1.4} ,$$

when 3.5 IN^3 of oil are pumped into the accumulator while $x = 0$ and after precharging.

For a 1.125 inch diameter piston,

$$A_p = \frac{\pi d^2}{4} = 1 \quad in^2 \quad .$$

If the friction loss in the pipes and fittings is neglected,

$$P_3 = P_2 - 14.7 \text{ psi}$$

since P_3 is gage pressure and P_2 is absolute pressure. Therefore,

$$T = \frac{I_4(\ddot{\theta}S/d)+\{P_{ap}(\frac{V_{max}}{V_{max}-3.5-(B_9+\theta B_{10})})^{1.4}-14.7\}\ e\ \{\cos\gamma + \frac{\theta S}{d}\sin\gamma\}}{d\{\cos\gamma + \frac{\theta S}{d}\sin\gamma\}}$$

Let

$$B_1 = I_4\ S/d$$

$$B_2 = d\cos\gamma$$

$$B_3 = S\sin\gamma$$

$$B_4 = \{P_{ap}(\frac{V_{max}}{V_{max}-3.5-(B_9+\theta B_{10})})^{1.4}-14.7\}e(\cos\gamma$$

$$+ \frac{\theta S}{d}\sin\gamma)$$

Then, the cable tension is given by the following equation;

$$T = \frac{\ddot{\theta}\ B_1 + B_4}{B_2 + \theta\ B_3} \equiv T_s \qquad (2.2)$$

Now combine Equations (2.1) and (2.2) for T to obtain:

$$\ddot{\theta} - \theta C_1 + C_2 + \left(\frac{\ddot{\theta} B_1 + B_4}{B_2 + \theta B_3}\right) (C_3 + \theta C_4) = 0$$

Let

$$B_5 = \left(\frac{1}{B_2 + \theta B_3}\right)(C_3 + \theta C_4)$$

$$B_6 = 1 + B_5 B_1$$

Hence,

$$\ddot{\theta} B_6 - \theta C_1 + C_2 + B_4 B_5 = 0$$

or

$$\ddot{\theta} = \frac{(\theta C_1 - C_2 - B_4 B_5)}{B_6} \qquad (2.3)$$

Equation 2.3 expresses the position of the probe in terms of the dynamic properties of the system. This equation will be used to design the system.

Two computer programs were written to calculate the response time, angular velocity, acceleration and torque of probe arm, tension of cable, vertical travel of probe, and pressure change of the hydraulic system. Figure 2.13 shows the response (i.e. the vertical travel) of the probe for two different precharge pressures (P_1 and P_2) in the accumulator. The response is shown for a 30.8 in^3 accumulator. A volumne of oil, $V'' = 3.5\ IN^3$, was pumped into the accumulator after precharging and while the hydraulic cylinder was fully extended, i.e.

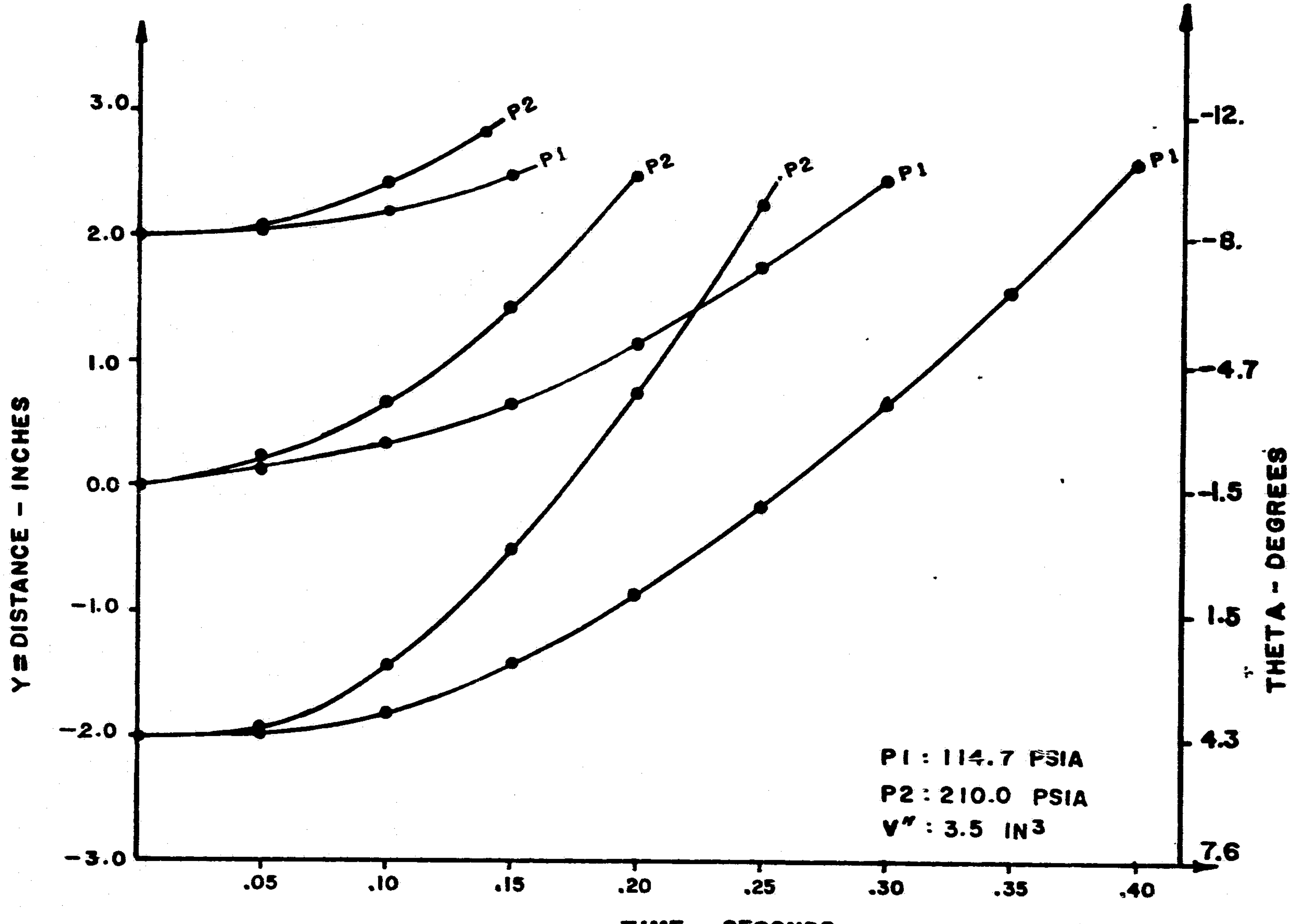


FIGURE 2.13 DYNAMIC RESPONSE OF RDRM PROBE FOR DIFFERENT ROOF HEIGHTS

$x = 0$. This produced pressures greater than precharge pressures at $x = 0$.

Figure 2.14 shows the relation between the angular position of the probe arm, theta, and the hydraulic pressure with two different precharge pressures (P_1 and P_2) and with two sizes of accumulators (V_1 and V_2). From the curves it can be seen that an accumulator volume of 30.8 in^3 and a precharge pressure of 114.7 psia will give a fairly smooth curve without building up a high pressure in the operating range of the probe arm. So, the recommended accumulator size is 30.8 in^3. The accumulator was filled with an oil volume V'', equal to 3.5 IN^3 after precharging and with the hydraulic cylinder fully extended.

Figure 2.15 shows the relation between precharge pressure in the accumulator and time required to rotate the probe arm from a position of $\theta_1 = 45$ degrees or $\theta_2 = -7.5$ degrees to obtain a certain angle when the probe will contact the coal roof which is theta equal to -10 degrees. From Figure 2.15 it can be seen that the minimum precharge pressure in the accumulator is 60 psia. This means that the precharge pressure below 60 psia will not be adequate to move the probe at all positions in the operating range. The influence of a small volume of oil (V', V'', V''') on the dynamic response is indicated. This volume of oil was pumped into the accumulator after precharging and with the hydraulic cylinder fully extended. Some excess of oil is required to make up for leakage through the hydraulic valves.

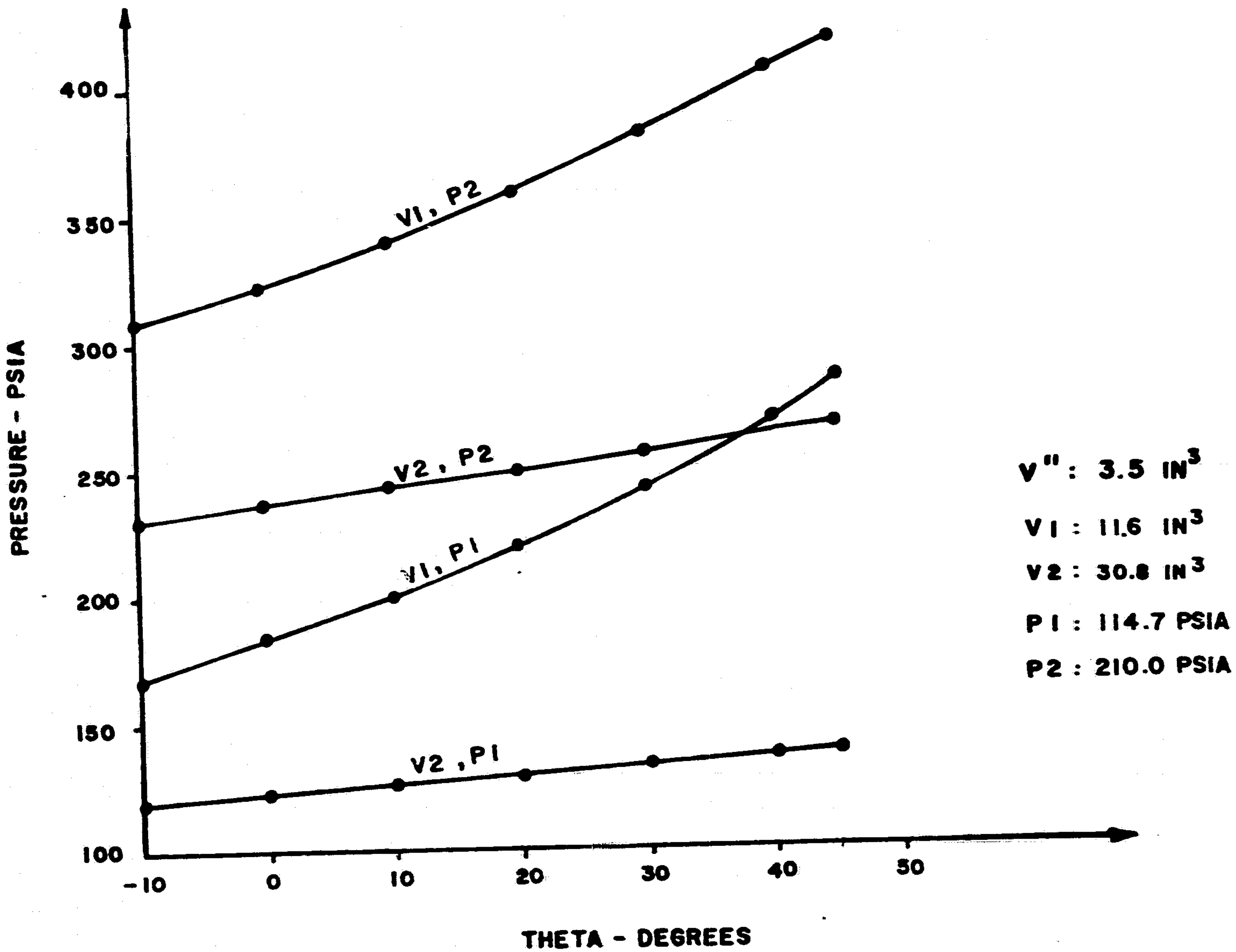


FIGURE 2.14 PROBE RESPONSE AS A FUNCTION OF PRECHARGE PRESSURE AND ACCUMULATOR SIZE

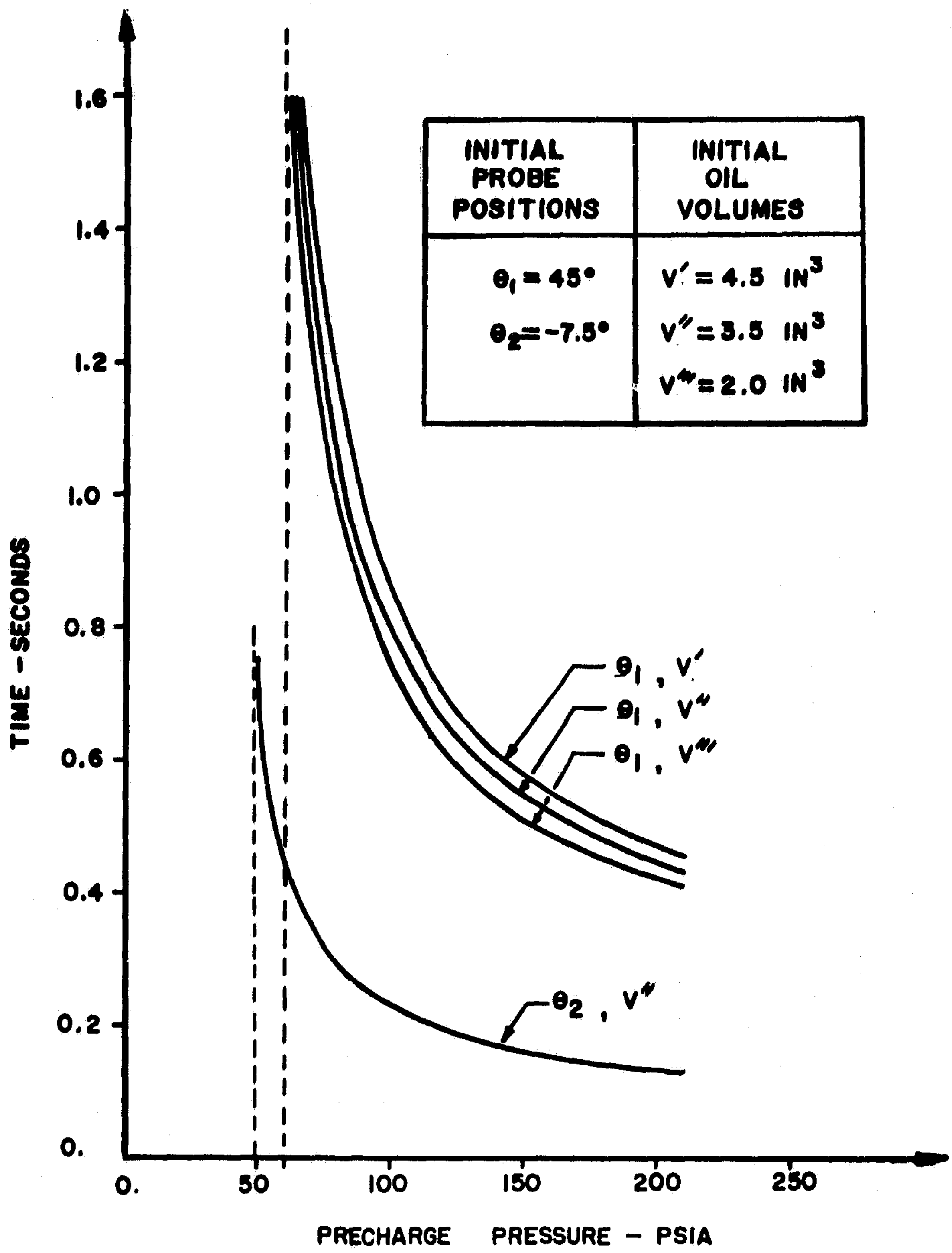


FIGURE 2.15 PROBE RESPONSE TIME VERSUS PRECHARGE PRESSURE

The modified Euler (predicator - corrector) method and Runge-Kutta 4th order method were used in the computer program to integrate the equation (2.3) for accuracy comparison. Both methods provide the same answer as shown in Appendix B.

2.3.6 Design of Linearized Visual Readout Linkage

To design a 4-bar mechanism to generate a desired function with four precision points or more, we might write the Freudenstein equation for these points (5). However, beyond the 4 points the calculations become so extensive that making them is impractical unless they are programed for a computer. In this paper, we include here one very practical approximate way of design for multiple - coordinated input and output - crank positions. The procedure, which is called the "overlay method", will be illustrated by the following example.

A 4-bar mechanism is to be designed so that the angular displacements of the two cranks will be related according to the following schedule:

	Degrees Rotation From Starting Position	
Position Number	First Crank	Second Crank
0	0	0
1	30	17
2	60	36
3	90	59
4	120	88

Procedure:

(1). On transparent paper make a layout, Figure 2.16, showing the

successive positions of the first crank. Use any convenient length for this crank. Assume a length for the connecting rod and draw the family of circle arcs of this radius with centers at the successive crankpin positions.

(2). Make a second layout, Figure 2.17, showing the successive positions of the second crank and a series of possible lengths for this crank.

(3). Fit the first layout over the second, as shown in Figure 2.18, trying to make the circle arcs of the first pass in proper order, through one of the series of possible crankpin positions of the second. It may be necessary to try other connecting-rod lengths, redrawing the first layout, before a satisfactory fit is obtained or the conclusion is drawn that none exists.

This is a good, practical procedure that will yield satisfactory results for many problems, especially those for which the tolerance on position of the output crank is of the order of 0.5 degrees or more.

Now, to return to our design problem, it is necessary to show the LWS operator a linearized scale of a ± 2 inch range with one inch increments for the distance which he must move the cutting drum. We need 5 points, i.e. 5 linear output crank positions from 5 non-linear input crank positions. Using the overlay method, we obtain a satisfactory fit for the visual scales of RDRM and LCF readout system as shown in Figure 2.7. The pointer pivot shaft may be directly connected to a linear rotary potentiometer if an electrical signal proportional to drum height correction is desired.

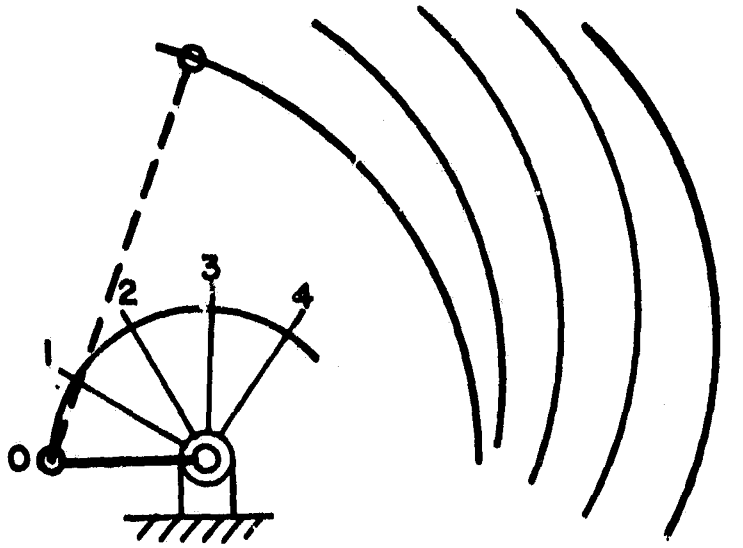


FIGURE 2.16 THE OVERLAY METHOD, THE SUCCESSIVE POINTS OF THE FIRST CRANK.

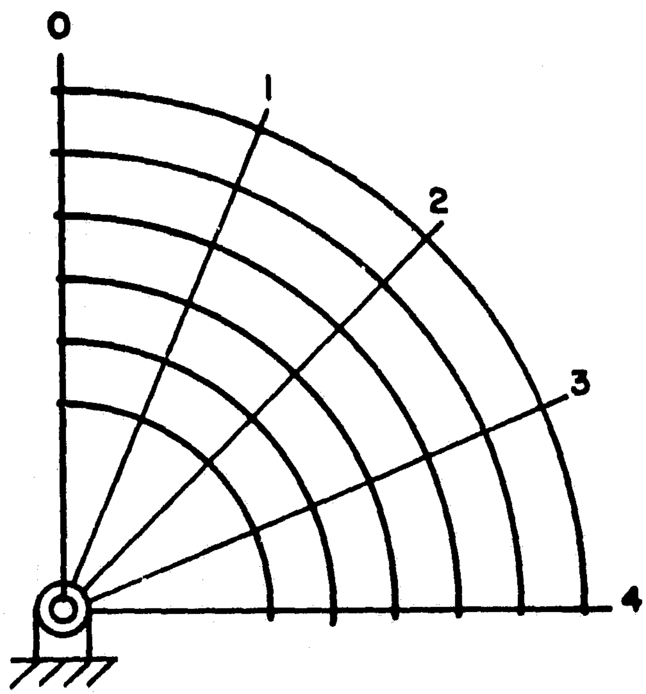


FIGURE 2.17 THE OVERLAY METHOD, THE REQUIRED POSITIONS OF THE SECOND CRANK.

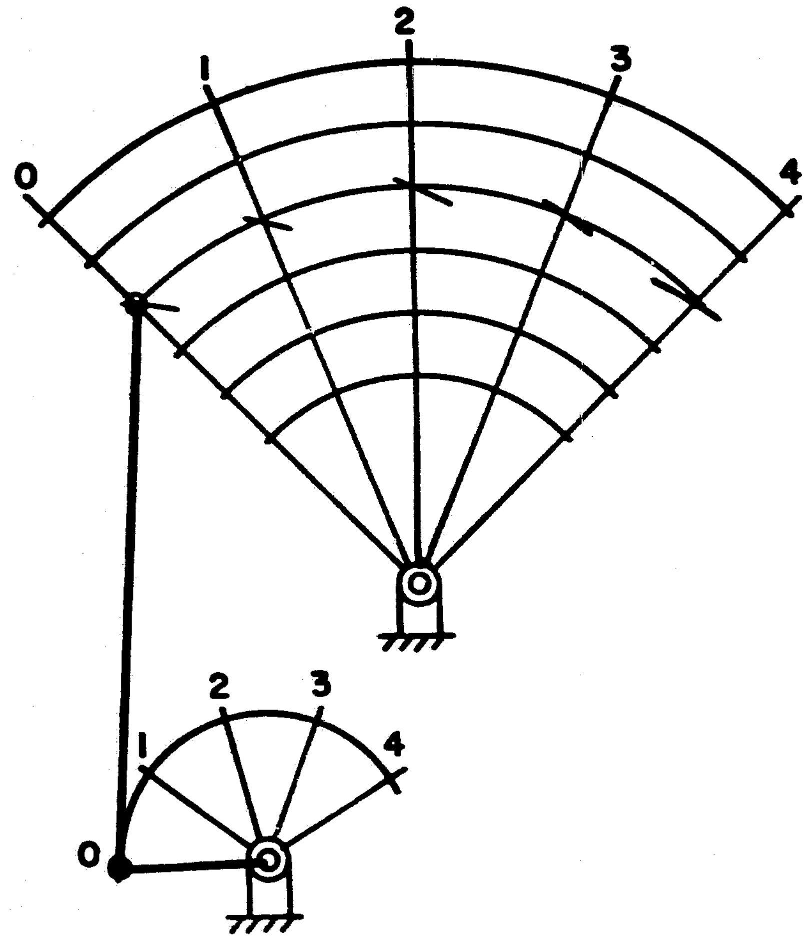


FIGURE 2.18 OVERLAY OF LAYOUTS IN FIGURE 2.16 AND FIGURE 2.17

CHAPTER III

DESIGN OF LAST CUT FOLLOWER REFERENCING MECHANISMS

3.1 General Description and Functional Requirements

It is desired to have the ceiling for the "present cut" within ± 2 inches of the ceiling of the "last cut". This control of the size of discontinuities in the roof surface (Figure 3.1) is required to avoid excessive tilting of the hydraulic roof supports.

The last cut follower mechanism, LCF, is designed to measure the distance from the ceiling of the last cut to the center of the front cutting drum. The difference in the height of the LCF probe above the drum center and the radius of the drum provide the distance, or error, in ceiling height between the last cut and the present cut. A visual pointer is provided which will indicate this "error" in front drum position so that the LWS operator can eliminate it by raising or lowing the front drum manually. But the design will be able to interface with a system which automatically controls the drum position. This mechanism is also designed to be stowable when used with the rear cutting drum and deployable when used with the front drum. It is also designed to withstand the severe environment in the coal mine.

3.2 Design Concepts

Two design concepts for the last cut follower are investigated, but only one is fully developed as a final design. Figure 3.1 and Figure 3.2 show these two concepts. Both concepts are installed

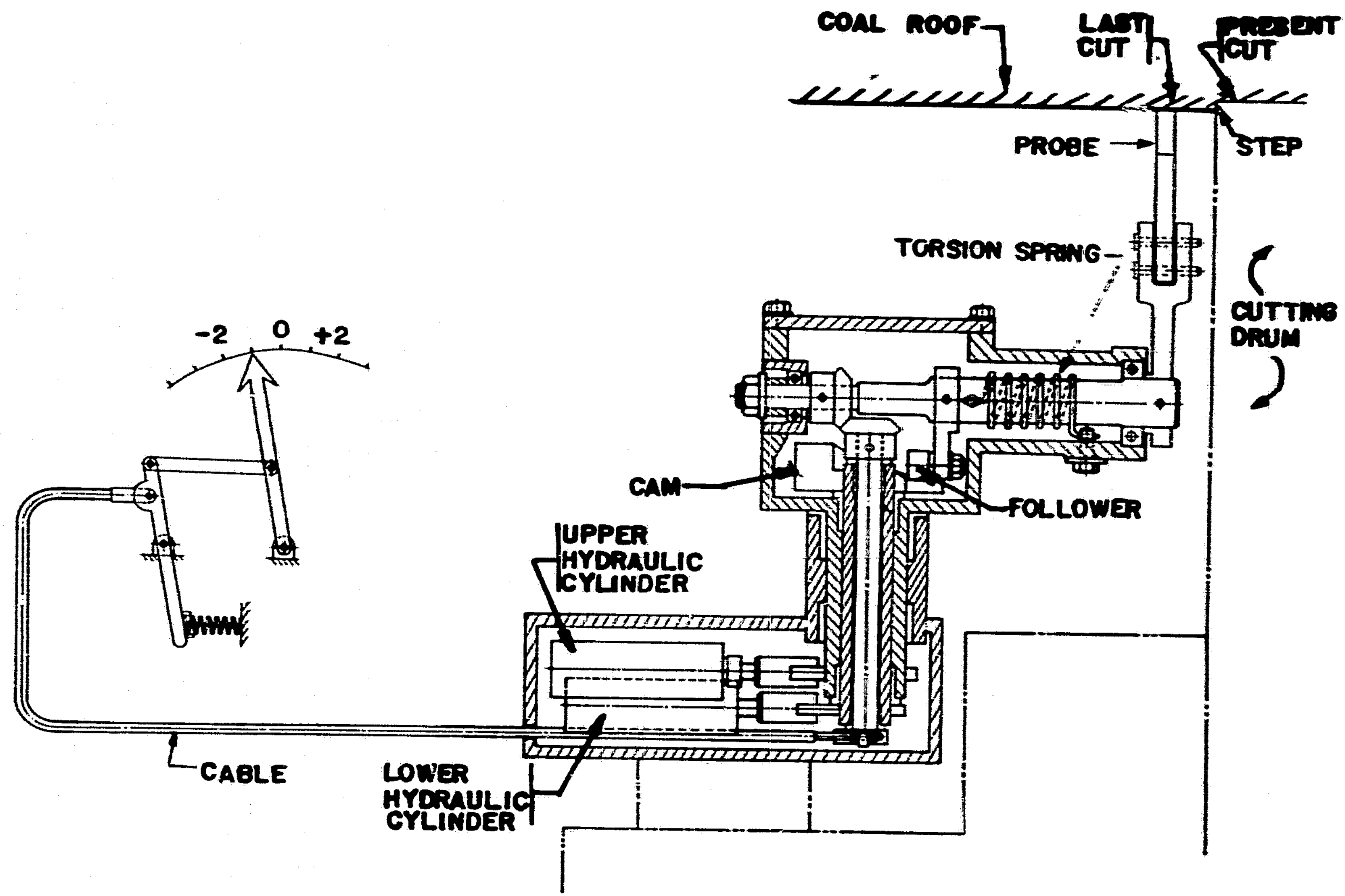


FIGURE 3.1 LAST CUT FOLLOWER MECHANISM WITH CAM AND FOLLOWER

on the same support tracks. The main difference between these two concepts is that the first one uses a cam follower, a cable under light spring tension to actuate the pointer, three concentric tubes, and two hydraulic cylinders in the base. The latter uses only one hydraulic cylinder in the base and a push-pull cable with a hydraulic cylinder to actuate it.

Figure 3.1 shows the lower hydraulic cylinder which drives the cam which rotates the probe arm down from contact with the roof. The probe attempts to exert a constant contact force on the coal roof because it is desired to have a constant acceleration of the probe as it moves into a void. This force is supplied by the spring on the pointer and by the torsion spring. The cam will keep the probe arm in the stow position while the upper housing is rotated. The upper hydraulic cylinder will rotate the upper portion of the mechanism from the deployed to the stow position and vice versa.

The second design, which is shown in Figure 3.2, is simpler than the design in Figure 3.1. The number of concentric shafts is reduced and the torsion spring is eliminated. This is the final design because the simplification will reduce cost and improve the manufacture ability significantly.

The probe is held against the coal surface by the force which originates in the LCF visual readout linkage, Figure 2.7. This cylinder is supplied with oil from the accumulator as the probe moves over the undulating roof surface. The force is transmitted from the cylinder to the probe via the system of levers, cable and

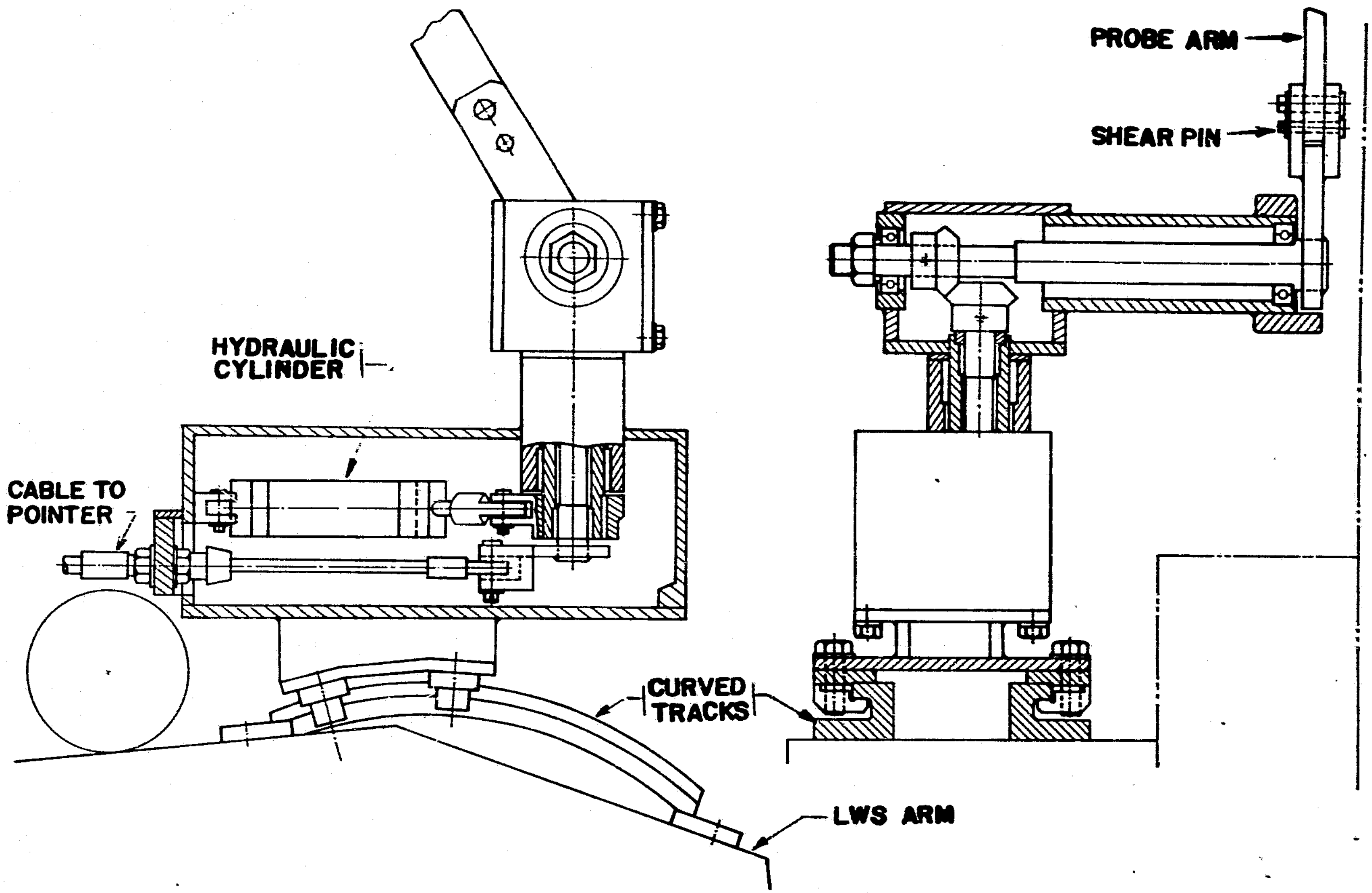


FIGURE 3.2 LAST CUT FOLLOWER MECHANISM WITHOUT CAM

gears. The cable is in tension when the probe is in the active or deployed position. The probe may be pulled into a stow position by actuation of the hydraulic cylinder in Figure 3.2 and by actuation of the hydraulic cylinder of the LCF visual readout linkage to place the cable in compression. The following sequence of events describe this operation. First, the probe arm is rotated downward from the roof surface to the horizontal position by pressurizing the rod end of the cylinder which places the cable in compression. Second, the cylinder in the base is pressurized on the head end to cause the top of the LCF support to rotate, the compression force of the cable continually forces the arm to remain in the horizontal position as the LCF support rotates.

A pointer, which moves over a linear scale, is attached to the cable so that the LWS operator can change the front drum height through use of this visual system. By using the overlay method (5), the response of the probe is linearized so that the distance on the scale of the pointer is directly proportional to the vertical distance traveled by the probe. To reduce wear and friction needle bearings and needle thrust bearings are used in this linkage.

To keep the mechanism in the vertical position and get the most correct readout, two curved tracks are developed. An error would be produced in the LCF reading if the LCF is not perpendicular to the roof of the mine because it would not indicate the perpendicular distance from the drum center to the roof.

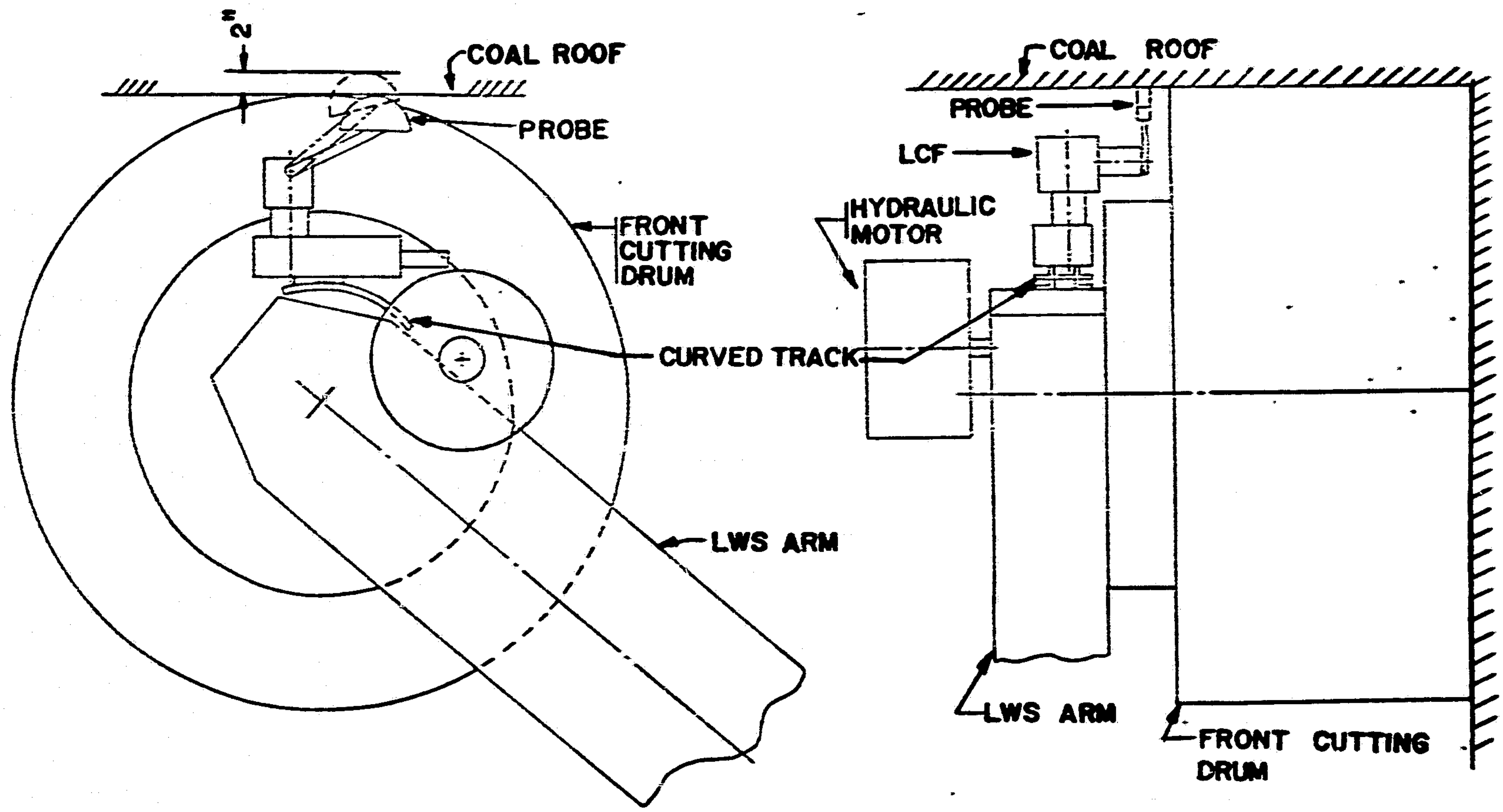
The mechanism is mounted on the tracks for a specific angle position of the ranging arm. When the angle of the ranging arm is changed, the whole mechanism must be relocated by loosening the bolts

on the LCF base. The center of the radius of the curved tracks is at the axis of the cutting drum. Thus, the mechanism can be relocated easily to the vertical position when the angle of the arm is changed. Since it is assumed that the coal seam depth is relatively constant, this track adjustment should not be required frequently. A general outline of this system is shown in Figure 3.3.

A shear pin is designed for the probe arm to protect the main body of the mechanism in case of a coal roof cave-in. Since the system does not involve a large inertia, the dynamic response of the system is omitted. The linearized visual readout mechanism is combined with the RDRM system as shown in Figure 2.7.

3.3 Hydraulic Circuits

There are two hydraulic circuits to operate the system. The purpose of the sensing circuit is to raise or lower the probe via the linear actuator, cable and bevel gears as shown in Figure 3.5. There is a pointer to show the probe height while the probe moves along the undulating roof profile. A relief valve is provided to prevent damage from roof cave-ins. An accumulator is also used in this circuit to provide the hydraulic cylinder with a steady supply of pressurized fluid. The angular deployment circuit is provided to rotate the probe arm 90 degrees from the deployed position to the stowed position or vise versa as shown in Figure 3.4.



FRONT VIEW   SIDE VIEW

FIGURE 3.3 GENERAL OUTLINE OF THE LCF

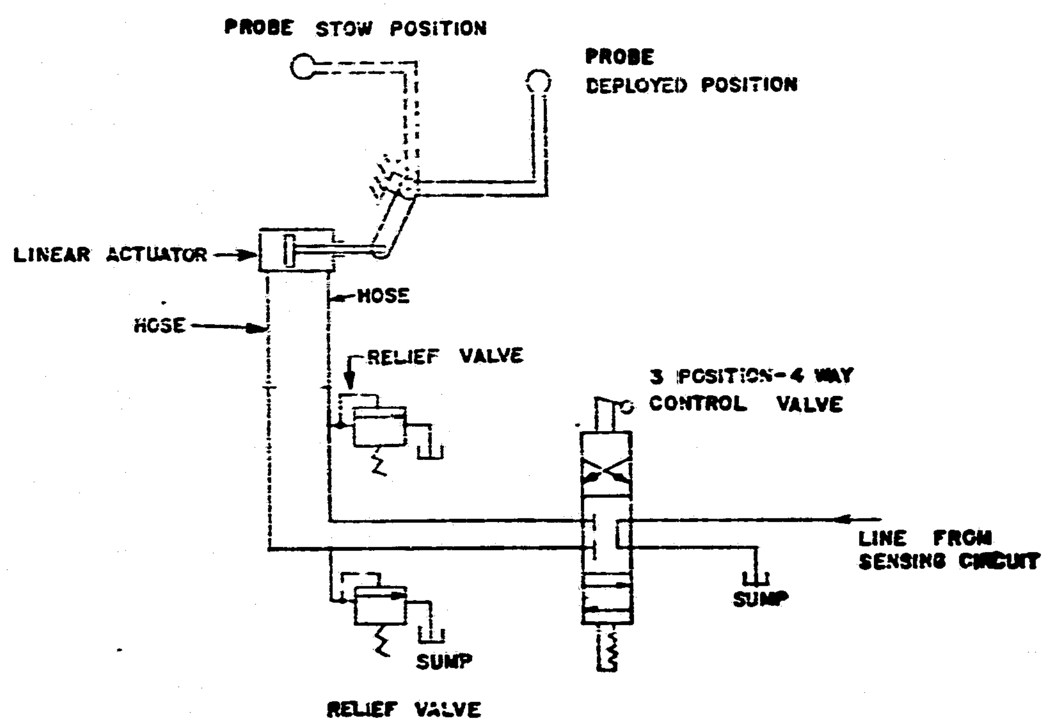


FIGURE 3.4 ANGULAR DEPLOYMENT CIRCUIT FOR PROSE
(LAST CUT FOLLOWER)

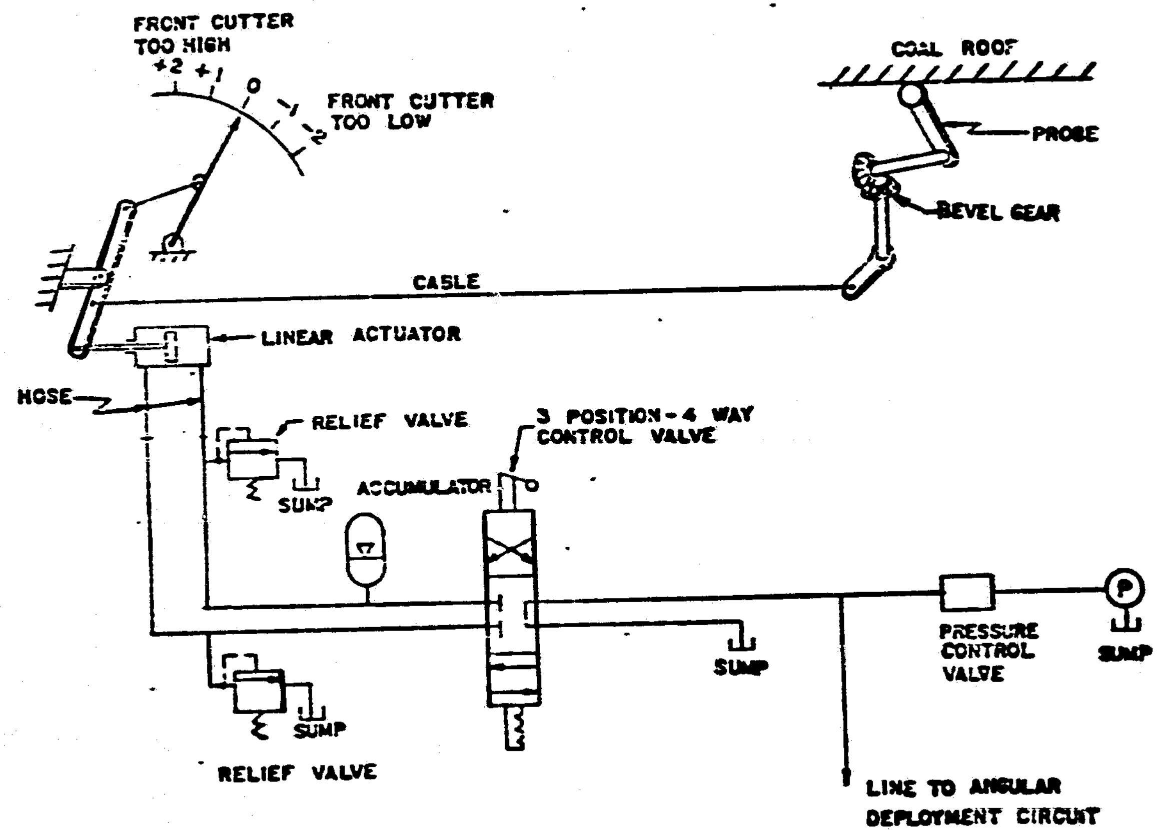


FIGURE 3.5. SENSING CIRCUIT (LAST CUT FOLLOWER)

CHAPTER IV

CONCLUSIONS AND RECOMMENDATIONS

Five design concepts for rear drum referencing mechanism and two design concepts for last cut follower mechanism are presented. Only one concept for each system is fully developed. A total of twenty-four design drawings, which are listed in Appendix A, are prepared for manufacturing. The final design concept for the RDRM is illustrated in Figure 2.5, while the final design for the LCF is shown in Figure 3.3. Outlines of the LWS with the RDRM and the LCF at their extended and retracted positions are shown in Figure 4.1.

The suspension system for both the RDRM and the LCF use hydropneumatic springs. The dynamic response characteristic of the RDRM is analyzed. The recommended accumulator size is 30.8 in^3, the precharge pressure is 114.7 psia, and the initial oil fill is $V'' = 3.5\ in^3$. The dynamic response of the LCF was not analyzed in detail.

The RDRM and the LCF may be remotely deployed or stowed.

It was not feasible to use the RDRM to perform the LCF function.

Visual indicators are provided to indicate the roof step between the last cut and the present cut and to indicate the required change in rear drum height.

An orderly procedure for deploying and retracting the RDRM and LCF is required to prevent interference.

Preliminary experiments should be conducted with the initial models to verify response time and to check the rate of oil leakage across the valves.

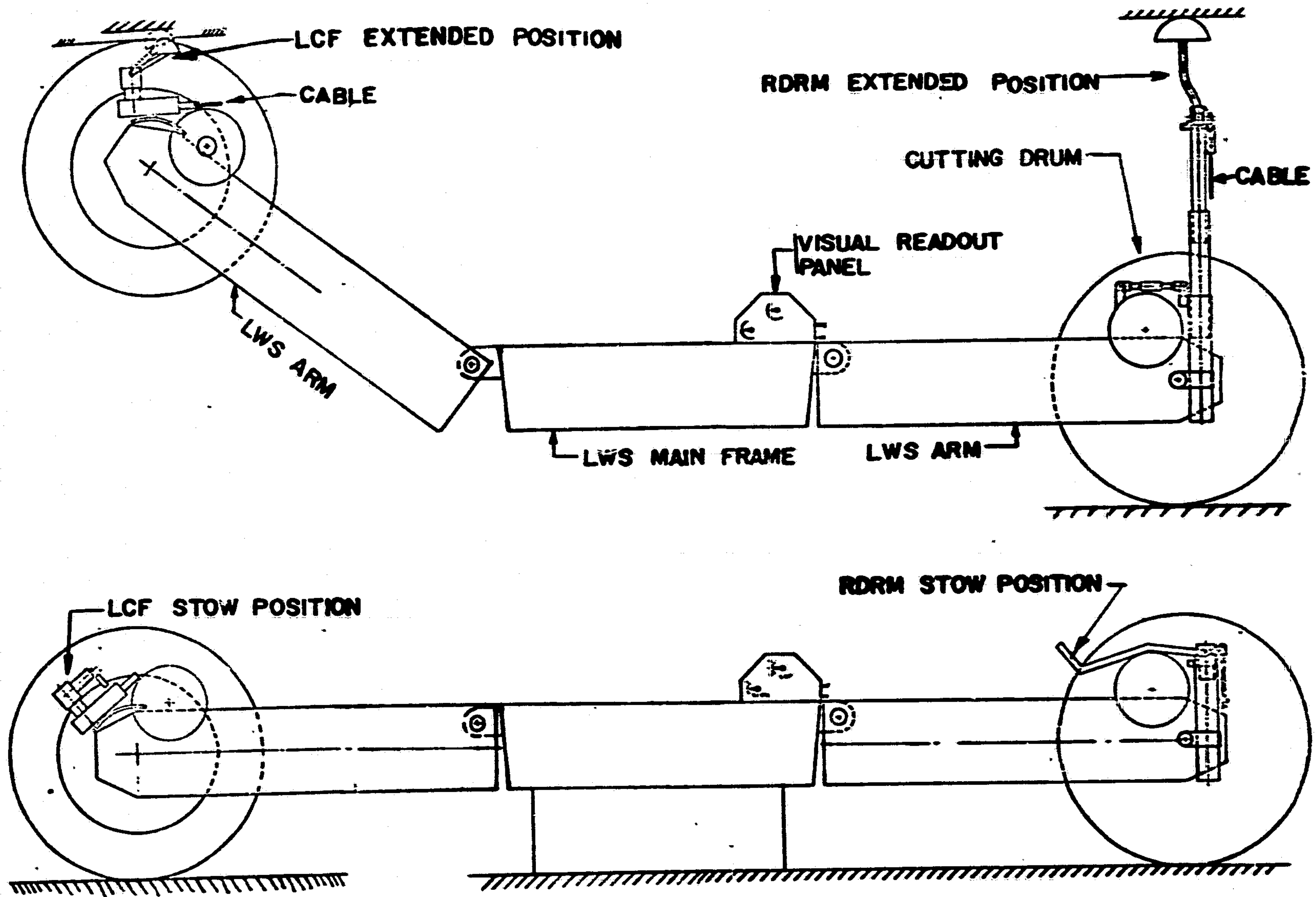


FIGURE 4.1 GENERAL ARRANGEMENT OF THE RDRM AND THE LCF AT THEIR EXTENDED AND RETRACTED POSITIONS

If the nucleonic coal detector is to be mounted to the LWS, the mounting system will probably require some changes to the RDRM and LCF mountings.

The performance calculations should be repeated to include friction loss in fluid flow. The equation for B5 as shown on Page 35 is correct, but a sign error exists in the computer program. The general conclusions do not appear to be significantly affected by the error.

APPENDIX A

LIST OF DRAWINGS

APPENDIX A

LIST OF DRAWINGS

LAYOUT NUMBER	DATE	DESCRIPTION
PB-001	Sept. '77	Hydraulic Controls for Main Stage
PB-002	Sept. '77	Position Control for Leakdown Prevention
PB-003	Oct. '77	Concept of Mechanism for Referencing Rear Drum of LWS - Mounted on Main Frame
PHB-001	Oct. '77	Concept for Mechanism for Referencing Drum of Longwall Shearer to a Given Surface
PHB-002	Oct. '77	Dual Parallel Linkage Concept for Supporting Probe.
PHB-003	Nov. '77	Telescoping Cylinder with Tubular Guide
PHB-004	Nov. '77	Concept for Mechanism for Referencing Rear Drum of LWS Using Expanding Linkage
PHB-005	Dec. '77	Sensor Arm, Pivot Head
PHB-006	Dec. '77	Pivot Head, Housing
PHB-007	Jan. '78	Last Cut Sensing Mechanism, Left-Hand
PHB-008	Jan. '78	Last Cut Sensing Mechanism, Right-Hand
PHB-009	Feb. '78	Probe, Mechanism for Referencing Rear Drum
PHB-010	Feb. '78	Parts for Last Cut Sensing Mechanism
PHB-011	Feb. '78	Referencing System for Rear Cutting Drum
PHB-012	Feb. '78	Arm, Sensor, Referencing System for Rear Drum

LAYOUT NUMBER	DATE	DESCRIPTION
PHB-013	Mar. '78	Parts, Mechanism for Referencing Rear Drum
PHB-014	Mar. '78	Parts, Mechanism for Referencing Rear Drum
PHB-015	Mar. '78	Parts, Last Cut Sensing Mechanism
PHB-016	Mar. '78	Flange and Shaft Assembly, Apparatus for Referencing Rear Drum
PHB-017	May '78	Supporting Shaft for Apparatus for Referencing Rear Drum
PHB-018	May '78	Parts, Apparatus for Referencing Rear Drum
PHB-019	May '78	Turnbuckle, Apparatus for Referencing Rear Drum
PHB-020	July '78	Rectangular Tubing, Mechanism for Referencing Rear Drum
PHB-021	July '78	Parts, Track, Last Cut Follower
PHB-022	Aug. '78	Track for Last Cut Follower
PHB-023	Aug. '78	Mechanism for Referencing Rear Drum
PHB-024	Aug. '78	Linearizing Mechanism for Visual Readout of Last Follower Signal
PHB-025	Sept. '78	Angular Deployment Circuit for Probe (Last Cut Follower)
PHB-026	Sept. '78	Angular Deployment Circuit for Probe and Sensing Circuit (Rear Drum Referencing Mechanism)
PHB-027	Oct. '78	Vertical Positioning Circuit for Different Roof Heights (Rear Drum Referencing Mechanism)
PHB-028	Oct. '78	Sensing Circuit for Probe (Last Cut Follower)

LAYOUT NUMBER	DATE	DESCRIPTION
PHB-029	Nov. '78	Linearizing Mechanisms for Visual Readout (Right Hand) (Last Cut Follower and Rear Drum Referencing Mechanism)
PHB-030	Nov. '78	Assembly of Sensing Mechanism for Rear Drum Referencing Mechanism

APPENDIX B

LIST OF COMPUTER PROGRAMS FOR

DYNAMIC ANALYSIS OF R.D.R.M.

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DYNAMIC ANALYSIS ON THE DESIGN OF A REAR DRUM REFERENCING MECHANISM
AND HYDRAULIC CIRCUIT OF LONGWALL SHEARER (A COAL MINE MACHINE)
THIS PROGRAM WILL ANALYZE THE RESPONSE OF TORQUE, TIME AND DISTANCE
FOR TRAVEL OF THE PROBE IN THE SYSTEM,TO DETERMINE APPROPRIATE GAS
PRESSURE IN ACCUMULATOR.

*****************************

PREDICTOR-CORRECTOR METHOD

*****************************

A (INCHES) LENGTH OF ARM OF PROBE
ALPHA (RADIAN) THE ANGLE BETWEEN THE ARM OF PROBE AND THE ARM
    CONNECTED EITH CABLE
B (INCHES) THE DISTANCE BETWEEN CENTER OF GRAVITY OF ARM OF PROBE
    AND ITS CENTER OF ROTATION.
BETA (RADIAN) THE ANGLE BETWEEN HORIZONTAL LINE AND ARM OF PROBE.
C (INCHES) VERTICAL DISTANCE BETWEEN THE TOP OF PROBE AND PROBE ARM
    ROTATING CENTER WHEN THETA IS ZERO.
D (INCHES) DISTANCE BETWEEN ARM ROTATING CENTER AND THE POINT
    CONNECTED TO CABLE.
E (INCHES) DISTANCE BETWEEN ARM ROTATING CENTER AND THE POINT
    CONNECTED TO PISTON ROD.
FR (LBS) FORCE OF COAL ROOF AGAINST PROBE.
GAMA (RADIAN) THE ANGLE BETWEEN VERTICAL LINE AND THE ARM OF FOUR-
    BAR LINKAGE WHICH CONNECTED TO CABLE WHEN THETA IS ZERO.
I2 (IN-LB-SEC**2) MASS MOMENT OF INERTIA OF PROBE AND ARM OF PROBE.
I4 (IN-LB-SEC**2) MASS MONMENT OF INERTIA OF PISTON AND PISTON ROD.
P (PAIA) ACCUMULATOR PRESSURE WHILE PROBE ARM ROTATING.
PAP (PSIA) PRECHARGED PRESSURE OF GAS IN ACCUMULATOR.
S (INCHES) DISTANCE BETWEEN PROBE ARM ROTATING CENTER AND THE POINT
    CONNECTED TO CABLE.
SHAI (RADIAN) INITIAL VALUE OF THETA.
T (SECOND) TIME REQUIRED FOR THE PROBE TRAVELLING.
THETA (DEGREE) PROBE ARM POSITION ANGLE.
TQ (IN-LBS) TORQUE OF THE PROBE ARM.
TS (LBS) TENSION OF CABLE.
V (INCHE**3) GAS VOLUME OF ACCUMULATOR AFTER INITIAL CHARGED WITH
    3.5 CUBIC INCHES OF OIL.
V1 (INCH**3) MAXIMUM VOLUME OF ACCUMULATOR.

Y (INCHES) PROBE VERTICAL TRAVELING LENGTH.
W2 (LBS) WEIGHT OF PROBE AND PROBE ARM.

REAL I2,I4, NEGBLE
RAD=3.1415925/180.
ALPHA=154.*RAD
BETA=132.2*RAD
GAMA=21.*RAD
SHAI=5.82*RAD
ALBT=BETA-ALPHA
A=27.8
B=21.6
C=20.594
D=3.8
E=2.75
FR=0.
I2=60.23
I4=0.485
PAP=114.7
S=3.8
V1=30.8
V=V1-3.5
W2=7.34
```

```
      T=0.
      DT=0.01
      Q1=45.*RAD
      QD1=0.
      QDD1=0.
      QDD2E=-0.01*RAD
      WRITE(6,10)
   10 FORMAT(9X,'TIME', 9X,'THETA',10X,'THETA', 8X,'THETA',10X,
     *'ZZ1',10X,'ZZ2',9X,'TS',9X,'TQ',5X,'ITERAT',5X,'Y',7X,
     *'P',/38X,'DOT',9X,'DOUBLE',/51X,'DOT',/)
  190 ITERAT=0
  150 CONTINUE
      QD2=(QDD2E+QDD1)*DT/2.+QD1
      Q2=(QD2+QD1)*DT/2.+Q1
      C1=(FR*A*SIN(BETA)+W2*B*SIN(BETA))/I2
      C2=(FR*A*COS(BETA)+W2*B*COS(BETA))/I2
      C3=S*COS(ALBT)/I2
      C4=S*SIN(ALBT)/I2
      B1=I4*S/D
      B2=D*COS(GAMA)
      B3=S*SIN(GAMA)
      B9=E*(SIN(SHAI+GAMA)-SIN(GAMA))
      B10=(S*E*COS(GAMA))/D
      B11=PAP*((V1/(V-(B9+B10*Q2)))**1.4)-14.7
      B4=B11*E*(COS(GAMA)+S*(Q2/D)*SIN(GAMA))
      B5=(C3-Q2*C4)/(B2+Q2*B3)
      B6=1.+B5*J1
      TS=(QDD2*J1+B4)/(B2+Q2*B3)
      TQ=-FR*A*COS(BETA+Q2)-W2*B*COS(BETA+Q2)-TS*S*COS(ALBT+Q2)
      QDD2=(Q2*C1-C2-B4*B5)/B6
      ZZ1=ABS(QDD2E-QDD2)
      NEGBLE=0.000000001
      ERROR=0.0000001
      B7=(B4*B5+C2)/B6
      B8=C1/B6
      IF(ZZ1.LT.NEGBLE) GO TO 200
      ZZ2=ABS(ERROR*QDD2)
      QDD2E=QDD2
      IF(ZZ2-ZZ1) 180,200,200
  180 CONTINUE
      IF(ITERAT.GT.50) GO TO 300
      ITERAT=ITERAT+1
      GO TO 150
  200 CONTINUE
      IF(Q2.LT.-0.2) GO TO 400
      QDD2E=(QDD2-QDD1)*DT/DT+QDD2
      BQ=BETA+Q1
      Y=A*SIN(BQ)-C
      Q1=Q2*180./3.14159
      QD1=QD2*180./3.14159
      QDD1=QDD2
      T=T+DT
  300 CONTINUE
      WRITE(6,320) T,Q1,QD1,QDD1,ZZ1,ZZ2,TS,TQ,ITERAT,Y,B11
  320 FORMAT(1X,4F14.6,2F14.10,F9.2,2X,F9.2,3X,I4,1X,2F9.3)
      Q1=Q1*3.14159/180.
      QD1=QD1*3.14159/180.
      GO TO 190
  400 STOP
      END
```

NO DIAGNOSTICS.

TIME	THETA	THETA DOT	THETA DOUBLE DOT	ZZ1	ZZ2	TS	TQ	ITERAT	Y	P
.010000	44.993748	-1.257565	-4.389731	.0000001192	.0000004390	99.89	-190.58	2	-19.235	138.664
.020000	44.968567	-3.772495	-4.383022	.0000000000	.0000004389	99.88	-190.59	2	-19.233	138.658
.030000	44.918301	-6.286917	-4.375605	.0000000596	.0000004388	99.87	-190.57	1	-19.221	138.635
.040000	44.842356	-8.800124	-4.365483	.0000000596	.0000004385	99.85	-190.81	1	-19.196	138.606
.050000	44.742355	-11.312712	-4.357655	.0000000000	.0000004383	99.82	-191.00	1	-19.160	138.567
.060000	44.616533	-13.823970	-4.379175	.0000001192	.0000004379	99.78	-191.21	1	-19.111	138.519
.070000	44.465572	-16.329925	-4.374909	.0000000596	.0000004375	99.74	-191.47	1	-19.050	138.461
.080000	44.290046	-18.835149	-4.369478	.0000000596	.0000004370	99.69	-191.77	1	-18.977	138.394
.090000	44.089193	-21.337357	-4.364558	.0000000000	.0000004364	99.64	-192.12	1	-18.892	138.317
.100000	43.863315	-23.835154	-4.355076	.0000000596	.0000004358	99.57	-192.50	1	-18.795	138.230
.110000	43.612478	-26.331153	-4.351105	.0000000000	.0000004351	99.51	-192.93	1	-18.685	138.134
.120000	43.336712	-28.821665	-4.343465	.0000000596	.0000004343	99.43	-193.39	1	-18.564	138.029
.130000	43.036060	-31.308212	-4.335155	.0000001192	.0000004335	99.35	-193.89	1	-18.431	137.914
.140000	42.710572	-33.789515	-4.326209	.0000000000	.0000004326	99.26	-194.42	1	-18.285	137.790
.150000	42.360296	-36.265501	-4.315609	.0000000596	.0000004317	99.16	-194.98	1	-18.128	137.657
.160000	41.986228	-38.735805	-4.305373	.0000000596	.0000004306	99.05	-195.57	1	-17.959	137.515
.170000	41.586598	-41.200065	-4.295511	.0000001192	.0000004296	98.95	-196.19	1	-17.778	137.363
.180000	41.161318	-43.657325	-4.284035	.0000000596	.0000004284	98.83	-196.84	1	-17.585	137.203
.190000	40.712452	-46.109037	-4.271957	.0000000596	.0000004272	98.71	-197.51	1	-17.380	137.033
.200000	40.239172	-48.553059	-4.259295	.0000001192	.0000004259	98.58	-198.21	1	-17.164	136.855
.210000	39.741457	-50.989555	-4.245935	.0000000596	.0000004246	98.45	-198.92	1	-16.936	136.667
.220000	39.219417	-53.418494	-4.232221	.0000001788	.0000004232	98.30	-199.65	1	-16.697	136.471
.230000	38.673127	-55.839257	-4.217553	.0000000000	.0000004218	98.16	-200.40	1	-16.446	136.267
.240000	38.102673	-58.251650	-4.202845	.0000000000	.0000004203	98.00	-201.15	1	-16.184	136.053
.250000	37.508135	-60.655341	-4.187515	.0000000596	.0000004188	97.84	-201.92	1	-15.911	135.832
.260000	36.889511	-63.050045	-4.171575	.0000000000	.0000004172	97.69	-202.69	1	-15.627	135.602
.270000	36.247153	-65.435474	-4.155141	.0000001192	.0000004155	97.50	-203.46	1	-15.332	135.364
.280000	35.580949	-67.811351	-4.138229	.0000002384	.0000004138	97.33	-204.24	1	-15.026	135.117
.290000	34.891065	-70.177404	-4.120855	.0000001192	.0000004121	97.14	-205.01	1	-14.710	134.863
.300000	34.177451	-72.533376	-4.103035	.0000000000	.0000004103	96.95	-205.77	1	-14.383	134.600
.310000	33.440389	-74.879014	-4.084785	.0000002384	.0000004085	96.76	-206.52	1	-14.046	134.330
.320000	32.679923	-77.214079	-4.065125	.0000000596	.0000004066	96.55	-207.26	1	-13.699	134.052
.330000	31.896151	-79.538340	-4.047071	.0000000000	.0000004047	96.35	-207.98	1	-13.343	133.767
.340000	31.089211	-81.851575	-4.027541	.0000001788	.0000004028	96.14	-208.69	1	-12.976	133.474
.350000	30.259155	-84.153575	-4.007551	.0000000000	.0000004008	95.92	-209.36	1	-12.600	133.174
.360000	29.406196	-86.444137	-3.987722	.0000001192	.0000003988	95.70	-210.01	1	-12.215	132.866
.370000	28.530359	-88.723075	-3.967272	.0000000000	.0000003967	95.47	-210.63	1	-11.822	132.552
.380000	27.631793	-90.990208	-3.946518	.0000000000	.0000003947	95.24	-211.21	1	-11.420	132.230
.390000	26.710614	-93.245370	-3.925481	.0000000596	.0000003925	95.00	-211.75	1	-11.009	131.902
.400000	25.766945	-95.488402	-3.904179	.0000000000	.0000003904	94.76	-212.25	1	-10.591	131.567
.410000	24.800907	-97.719159	-3.882531	.0000000596	.0000003883	94.51	-212.71	1	-10.165	131.225
.420000	23.812523	-99.937505	-3.860857	.0000000000	.0000003861	94.25	-213.11	1	-9.732	130.877
.430000	22.802219	-102.143315	-3.838475	.0000000000	.0000003839	94.00	-213.46	1	-9.292	130.523
.440000	21.769520	-104.335478	-3.815707	.0000000596	.0000003817	93.74	-213.75	1	-8.846	130.162
.450000	20.715553	-106.515392	-3.794371	.0000000000	.0000003794	93.49	-213.98	1	-8.394	129.795
.460000	19.639546	-108.684654	-3.771886	.0000000596	.0000003772	93.21	-214.15	1	-7.937	129.423
.470000	18.541928	-110.839118	-3.749273	.0000000000	.0000003749	92.93	-214.25	1	-7.474	129.044
.480000	17.422828	-112.980795	-3.725551	.0000000000	.0000003727	92.65	-214.28	1	-7.007	128.660
.490000	16.282377	-115.109497	-3.703745	.0000000596	.0000003704	92.37	-214.23	1	-6.536	128.270
.500000	15.120705	-117.224039	-3.680459	.0000000000	.0000003681	92.08	-214.10	1	-6.061	127.875
.510000	13.937943	-119.327348	-3.657929	.0000000000	.0000003658	91.79	-213.80	1	-5.584	127.475
.520000	12.734223	-121.415608	-3.634967	.0000000000	.0000003635	91.50	-213.59	1	-5.104	127.070
.530000	11.509577	-123.492739	-3.611995	.0000000000	.0000003612	91.20	-213.21	1	-4.622	126.659
.540000	10.264435	-125.555550	-3.589031	.0000000000	.0000003589	90.90	-212.73	1	-4.140	126.244
.550000	8.998529	-127.605441	-3.566094	.0000000000	.0000003566	90.60	-212.15	1	-3.657	125.824
.560000	7.712391	-129.642133	-3.543205	.0000000000	.0000003543	90.29	-211.48	1	-3.174	125.400
.570000	6.405653	-131.665670	-3.520379	.0000000000	.0000003520	89.98	-210.71	1	-2.692	124.971
.580000	5.079143	-133.675134	-3.497639	.0000000596	.0000003498	89.66	-209.84	1	-2.212	124.538
.590000	3.732394	-135.673698	-3.475002	.0000000000	.0000003475	89.35	-208.86	1	-1.734	124.100
.600000	2.365734	-137.659276	-3.452487	.0000000000	.0000003452	89.03	-207.77	1	-1.259	123.659
.610000	.979293	-139.629693	-3.430113	.0000000000	.0000003430	88.70	-206.57	1	-.788	123.213
.620000	-.426882	-141.589036	-3.407895	.0000000596	.0000003408	88.38	-205.25	1	-.322	122.764
.630000	-1.852423	-143.535204	-3.385655	.0000000000	.0000003385	88.05	-203.82	1	.139	122.311
.640000	-3.297463	-145.468697	-3.364010	.0000000000	.0000003364	87.71	-202.28	1	.593	121.854
.650000	-4.761738	-147.390133	-3.342375	.0000001192	.0000003342	87.38	-200.62	1	1.040	121.394
.660000	-6.245184	-149.299038	-3.320970	.0000000596	.0000003321	87.04	-198.83	1	1.479	120.931
.670000	-7.747658	-151.195751	-3.299811	.0000000000	.0000003300	86.70	-196.93	1	1.910	120.465
.680000	-9.269039	-153.080416	-3.278915	.0000000000	.0000003279	86.36	-194.90	1	2.330	119.995
.690000	-10.809206	-154.953188	-3.258299	.0000000596	.0000003258	86.02	-192.76	1	2.739	119.523

OFIN

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DYNAMIC ANALYSIS ON THE DESIGN OF A REAR DRUM REFERENCING MECHANISM
AND HYDRAULIC CIRCUIT OF LONGWALL SHEARER (A COAL MINE MACHINE)

THIS PROGRAM WILL ANALYZE THE RESPONSE OF TORQUE, TIME AND DISTANCE
FOR TRAVEL OF THE PROBE IN THE SYSTEM,TO DETERMINE APPROPRIATE GAS
PRESSURE IN ACCUMULATOR.

***************************

RUNGE-KUTTA 4TH ORDER METHOD

***************************

A (INCHES) LENGTH OF ARM OF PROBE.
ALPHA (RADIAN) THE ANGLE BETWEEN THE ARM OF PROBE AND THE ARM
    CONNECTED EITH CABLE.
B (INCHES) THE DISTANCE BETWEEN CENTER OF GRAVITY OF ARM OF PROBE
    AND ITS CENTER OF ROTATION.
BETA (RADIAN) THE ANGLE BETWEEN HORIZONTAL LINE AND ARM OF PROBE.
C (INCHES) VERTICAL DISTANCE BETWEEN THE TOP OF PROBE AND PROBE ARM
    ROTATING CENTER WHEN THETA IS ZERO.
D (INCHES) DISTANCE BETWEEN ARM ROTATING CENTER AND THE POINT
E (INCHES) DISTANCE BETWEEN ARM ROTATING CENTER AND THE POINT
    CONNECTED TO PISTON ROD.
FR (LBS) FORCE OF COAL ROOF AGAINST PROBE.
GAMA (RADIAN) THE ANGLE BETWEEN VERTICAL LINE AND THE ARM OF FOUR-
    BAR LINKAGE WHICH CONNECTED TO CABLE WHEN THETA IS ZERO.
I2 (IN-LB-SEC**2) MASS MOMENT OF INERTIA OF PROBE AND ARM OF PROBE.
I4 (IN-LB-SEC**2) MASS MONMENT OF INERTIA OF PISTON AND PISTON ROD.
P (PAIA) ACCUMULATOR PRESSURE WHILE PROBE ARM ROTATING.
PAP (PSIA) PRECHARGED PRESSURE OF GAS IN ACCUMULATOR.
S (INCHES) DISTANCE BETWEEN PROBE ARM ROTATING CENTER AND THE POINT
    CONNECTED TO CABLE.
SHAI (RADIAN) INITIAL VALUE OF THETA.
T (SECOND) TIME REQUIRED FOR THE PROBE TRAVELLING.
THETA (DEGREE) PROBE ARM POSITION ANGLE.
TQ (IN-LBS) TORQUE OF THE PROBE ARM.
TS (LBS) TENSION OF CABLE.
V (INCHE**3) GAS VOLUME OF ACCUMULATOR AFTER INITIAL CHARGED WITH
    3.5 CUBIC INCHES OF OIL.
V1 (INCH**3) MAXIMUM VOLUME OF ACCUMULATOR.
Y (INCHES) PROBE VERTICAL TRAVELING LENGTH.
W2 (LBS) WEIGHT OF PROBE AND PROBE ARM.

REAL I2,I4,K1,K2,K3,K4
RAD=3.1415925/180.
ALPHA=154.*RAD
BETA=132.2*RAD
GAMA=21.*RAD
SHAI=5.82*RAD
ALBT=BETA-ALPHA
A=27.8
B=21.6
C=20.594
D=3.8
DT=0.005
E=2.75
FR=0.
I2=60.23
I4=0.485
PAP=114.7
Q2=45.*RAD
QD2=0.
S=3.8
T=0.
V1=30.8
V=V1-3.5
W2=7.34
```

```
      WRITE(6,300)
  300 FORMAT(10X,'TIME',10X,'THETA',10X,'THETA',10X,'THETA',10X,'TENSION
     *', 7X,'TORQUE ',10X,'Y',14X,'P',/40X,'DOT',10X,'DOUBLE',/55X,'DOT'
     *,/)
      DO 10 I=1,1000
      T=T+DT
      DT=DT+0.001
      C1=(FR*A*SIN(BETA)+W2*B*SIN(BETA))/I2
      C2=(FR*A*COS(BETA)+W2*B*COS(BETA))/I2
      C3=S*COS(ALBT)/I2
      C4=S*SIN(ALBT)/I2
      B1=I4*S/D
      B2=D*COS(GAMA)
      B3=S*SIN(GAMA)
      B9=E*(SIN(SHAI+GAMA)-SIN(GAMA))
      B10=(S*E*COS(GAMA))/D
      B11=PAP*((V1/(V-(B9+B10*Q2)))**1.4)-14.7
      B4=B11*E*(COS(GAMA)+S*(Q2/D)*SIN(GAMA))
      B5=(C3-Q2*C4)/(B2+Q2*B3)
      B6=1.+B5*B1
      QDD2=(Q2*C1-C2-B4*B5)/B6
      K1=DT*QDD2
      Q22=Q2+(QD2*DT/2.)+DT*K1/8.
      B11=PAP*((V1/(V-(B9+B10*Q22)))**1.4)-14.7
      B4=B11*E*((COS(GAMA)+S*(Q22/D)*SIN(GAMA)))
      B5=(C3-Q22*C4)/(B2+Q22*B3)
      B6=1.+B5*B1
      QDD2=(Q22*C1-C2-B4*B5)/B6
      K2=DT*QDD2
      Q23=Q2+(DT*QD2/2.)+DT*K1/8.
      B11=PAP*((V1/(V-(B9+B10*Q23)))**1.4)-14.7
      B4=B11*E*((COS(GAMA)+S*(Q23/D)*SIN(GAMA)))
      B5=(C3-Q23*C4)/(B2+Q23*B3)
      B6=1.+B5*B1
      QDD2=(Q23*C1-C2-B4*B5)/B6
      K3=DT*QDD2
      Q24=Q2+DT*QD2+DT*K3/2.
      B11=PAP*((V1/(V-(B9+B10*Q24)))**1.4)-14.7
      B4=B11*E*((COS(GAMA)+S*(Q24/D)*SIN(GAMA)))
      B5=(C3-Q24*C4)/(B2+Q24*B3)
      B6=1.+B5*B1
      QDD2=(Q24*C1-C2-B4*B5)/B6
      K4=DT*QDD2
      Q2=Q2+DT*(QD2+(K1+K2+K3)/6.)
      QD2=QD2+(K1+2.*K2+2.*K3+K4)/6.
      B7=(B4*B5+C2)/B6
      B8=C1/B6
      BQ=BETA+Q2
      Y=A*SIN(BQ)-C
      TS=(QDD2*B1+B4)/(B2+Q2*B3)
      TQ=-FR*A*COS(BETA+Q2)-W2*B*COS(BETA+Q2)-TS*S*COS(ALBT+Q2)
      Q2=Q2*180./3.14159
      QD2=QD2*180./3.1416
      IF(Q2.LT.-14.) GO TO 400
      WRITE(6,320) T,Q2,QD2,QDD2,TS,TQ,Y,B11
  320 FORMAT(1X,8F15.6)
      Q2=Q2*3.14159/180.
      QD2=QD2*3.1416/180.
   10 CONTINUE
  400 STOP
      END
```

NO DIAGNOSTICS.

ORIGINAL PAGE IS
OF POOR QUALITY

TIME	THETA	THETA DOT	THETA DOUBLE DOT	TENSION	TORQUE	Y	P
.005000	44.995508	-1.509121	-4.389781	99.888046	-190.538116	-19.233778	138.664312
.011000	44.978782	-3.269645	-4.389309	99.883400	-190.567783	-19.225672	138.657881
.018000	44.944576	-5.281348	-4.388346	99.873909	-190.628437	-19.209096	138.644735
.026000	44.886851	-7.543852	-4.386721	99.857692	-190.730568	-19.181128	138.622557
.035000	44.798857	-10.056576	-4.384245	99.833479	-190.885868	-19.138485	138.588751
.045000	44.673040	-12.818665	-4.380709	99.798590	-191.105972	-19.077526	138.540440
.056000	44.501149	-15.829032	-4.375887	99.750960	-191.407310	-18.994255	138.474485
.068000	44.274195	-19.085069	-4.369535	99.688120	-191.800735	-18.884332	138.387472
.081000	43.982458	-22.587887	-4.361394	99.607433	-192.301281	-18.743076	138.275751
.095000	43.615556	-26.331944	-4.351192	99.506095	-192.922581	-18.565485	138.135435
.110000	43.152361	-30.315194	-4.338650	99.381141	-193.677292	-18.346246	137.962429
.126000	42.611121	-34.533916	-4.323480	99.229472	-194.575393	-18.079767	137.752443
.143000	41.949432	-38.983664	-4.305397	99.047874	-195.628296	-17.760206	137.501036
.161000	41.164284	-43.659210	-4.284117	98.833051	-196.837856	-17.381513	137.203648
.180000	40.242096	-48.554476	-4.259365	98.581627	-198.205082	-16.937500	136.855621
.200000	39.168755	-53.662495	-4.230886	98.290198	-199.723885	-16.421910	136.452265
.221000	37.929659	-58.975369	-4.198447	97.955386	-201.380600	-15.828530	135.988905
.243000	36.509777	-64.484253	-4.161846	97.573827	-203.152203	-15.151331	135.460926
.266000	34.893696	-70.179356	-4.120925	97.142252	-205.004696	-14.384648	134.863842
.290000	33.065688	-76.049963	-4.075574	96.657541	-206.901163	-13.523411	134.193344
.315000	31.009773	-82.084437	-4.025742	96.116712	-208.750122	-12.563441	133.445389
.341000	28.709784	-88.270547	-3.971448	95.517018	-210.503597	-11.501814	132.616238
.368000	26.149437	-94.595084	-3.912738	94.855988	-212.055794	-10.337318	131.702543
.396000	23.312402	-101.044511	-3.849945	94.131441	-213.291771	-9.070092	130.701399
.425000	20.182364	-107.604900	-3.783196	93.341554	-214.076931	-7.706778	129.610390
.455000	16.743090	-114.262212	-3.712920	92.494974	-214.257046	-6.252271	128.427702
.486000	12.978494	-121.002551	-3.639603	91.560360	-213.659389	-4.719585	127.152050
.518000	8.872629	-127.812485	-3.563840	90.557390	-212.005066	-3.126288	125.782831
.551000	4.409825	-134.679377	-3.486340	89.505783	-209.362827	-1.496428	124.320080
.585000	-.425393	-141.591763	-3.407925	88.375761	-205.254581	.138444	122.764490
.620000	-5.648261	-148.539762	-3.329529	87.177072	-199.563057	1.738279	121.117418
.656000	-11.273807	-155.515514	-3.252193	85.913417	-192.001286	3.253674	119.380852

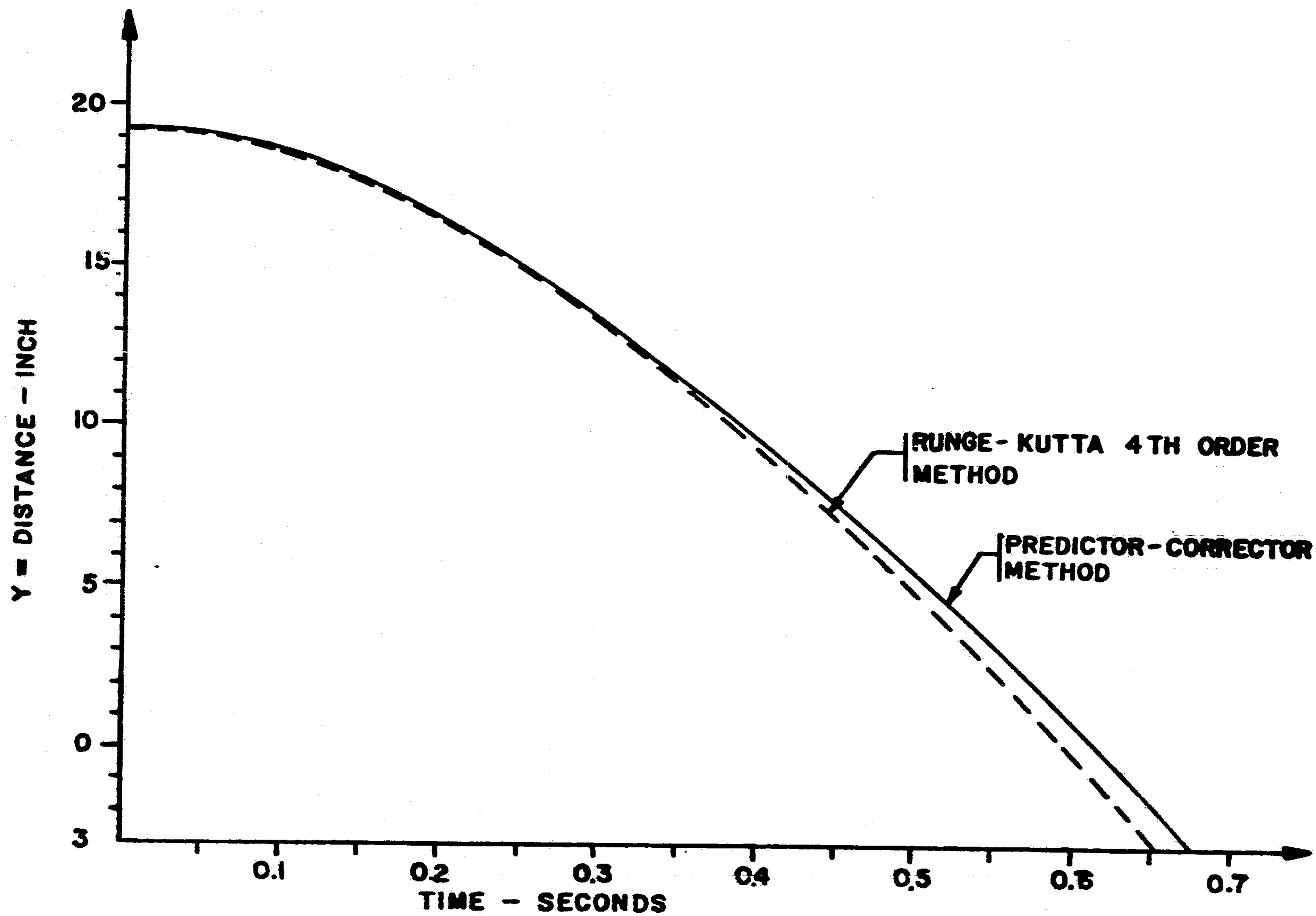

FIGURE B.1 COMPARISION OF INTEGRATION METHODS

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